

# Coordination under Uncertainty and Noisy Communication: a Generalized Email Game \*

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## Abstract

Which information transmission protocols improve coordination under uncertainty and noisy communication? Theory is indeterminate between an inefficient "tacit" equilibrium, where information is ignored, and an efficient "vocal" equilibrium, where players act on it. We test this in a laboratory experiment based on a generalized e-mail game, exogenously varying the message-generation rule across three protocols. Vocal behavior rises with the incentive to take the risky action, and relative to an automatic protocol, voluntary messaging significantly improves coordination. However, a sunk cost to sending reduces vocality by inducing senders to opt out. These patterns suggest that voluntariness credibly signals players' intent to coordinate via forward induction, and that the value of cost-free signaling for equilibrium selection hinges on the alignment of interests.

# 1 Introduction

Many economic practices are coordinative. Markets, organizations, and public institutions often require multiple agents to take complementary actions to achieve common goals. However, coordination can fail even when an obviously efficient outcome exists, as players face a minimum-effort problem: everyone must contribute for success, but each fears others will shirk, so the safe choice is inaction. Unlike a tension between self-interest and social optimum in the Prisoners' Dilemma, the crucial question here is equilibrium selection. When both all-shirk and all-contribute constitute an equilibrium, what factors determine which one players play out and what policies direct them to the latter, efficient outcome? Experimental evidence on Minimum Effort Games shows that strategic uncertainty sometimes leads players to choose the least possible effort. In Macroeconomics, bank run is also modeled as resulting from the bad equilibrium where a sufficiently high proportion of the investors simultaneously choose to withdraw their deposits (Diamond and Dybvig, 1983), whereas they could have coordinated on the good equilibrium by not withdrawing.

Challenge to coordination is even more pronounced in incomplete information settings where players initially hold partial and potentially different views of the same objective truth and hence might not know the right time for taking an action. Recent experiments on cheap talk in coordination games demonstrate that pre-play communication can steer play toward the efficient outcome. Avoyan (2023) shows in a two-player global game under incomplete information that allowing players to share their intended action before actual choices decreases wasteful miscoordination and increases the rate of coordinated attack. Despite positive findings, there lacks universal agreement on the optimal format of communication, such as timing, wide vs. constrained message space, and whether players can customize content as in an open chat box. Which combination of these rules make messages credible for players to act on?

To answer this question, this paper considers a noisy communication process in a highly structured manner and investigates how it shapes equilibrium selection in coordination games

under incomplete information. From a designer perspective, I look at how different features of the communication protocol affect players' interpretation of information generated by the protocol, which in turn induces different behavior and coordinative efficiency. I take the two-player coordination game from Rubinstein's Electronic Mail Game (henceforth Email Game, 1989) but vary its message-generation rules. Importantly, the new game, called Single-Cap Email Game, restricts communication to a one-shot message that may be lost with a small probability. Following Binmore and Samuelson (2001), this game accounts for a situation that sending a message to the partner can be a player's voluntary and sometimes costly decision, thereby conveying different meaning than one generated automatically.

In this simple communication protocol with one-shot message, which design features make the message credible enough to shift behavior toward efficient coordination despite noise? The lab experiment implements this game and tests for equilibrium selection between the inefficient "tacit" and the efficient "vocal". In the game, a binary state of nature, either good or bad, determines when joint risk-taking is efficient. Two players simultaneously choose between a safe action and a risky action that is jointly efficient in the good state. Only one of them is initially informed of the state, while the other is uninformed. In the good state, the informed player may send a message revealing the state to the uninformed player, which is subject to a small probability of getting lost. Using a  $3 \times 3$  between-subject design, I vary exogenously how this one-shot message is generated, for each incentive strength for the risky action denoted "temptation" (*Low/Medium/High*). The *Automatic* protocol auto-sends the good-state message. In *Voluntary*-type protocols, the informed player chooses whether to send, and sending is costless in *Voluntary-Free* but costly to the sender in *Voluntary-Costly*.

When information must travel through noisy and constrained channels – email, messaging platforms, automated alerts – coordination can fail not only because messages are lost, but also because players hesitate to act, fearing others never received them. The mechanical noise compounds with the innate strategic tension and may cause a Pareto-improving joint action to unravel. The experiment searches for the protocol best in resolving this tension. The

central performance measure is vocality, defined as how often players take the efficient action after receiving positive information generated by each type of protocol. Three hypotheses follow. First, vocality should increase as temptation rises. Second, fixing temptation level, *Voluntary* protocols should result in higher vocality than *Automatic* because a voluntary message conveys the sender's intent of joint risk-taking, in addition to the state. Third, for a given temptation, *Voluntary-Costly* should outperform *Voluntary-Free* because a message backed by a sunk cost commitment should be more credible than a free, cheap-talk-like message.

As expected, vocality increases with temptation, consistent with the notion of basin of attraction in equilibrium selection. Voluntary message induces more vocal behavior than automatic delivery, in line with the second prediction. However, the *Voluntary-Costly* protocol performed much worse than expected. Although the sunk cost makes the message slightly more credible *conditional on sending*, it also discourages message adoption as almost half of the informed players opt out in the first place, especially when strategic uncertainty is high. The results indicate an extensive-intensive margin trade-off between adoption and credibility and shed light on the behavioral role of sunk cost in economics practices more broadly. The findings are partially consistent with forward induction where a player's past moves may affect beliefs in a later subgame. While forward induction usually requires money-burning, here with aligned interests, voluntariness alone carries the information content and directs play toward efficiency.

The rest of the paper is organized as follows. Section 2 formalizes the Single-Cap Email Game under three different communication protocols and its relation to Rubinstein's. Section 3 provides the experimental design. Section 4 presents preliminary results comparing efficiency performance across the protocols. Section 5 concludes.

<i>G<sub>a</sub> with prob (1 - p)</i>		
state a	A	B
A	<b>M, M</b>	<b>0, -L</b>
B	<b>-L, 0</b>	<b>0, 0</b>

<i>G<sub>b</sub> with prob p &lt; <math>\frac{1}{2}</math></i>		
state b	A	B
A	<b>0, 0</b>	<b>0, -L</b>
B	<b>-L, 0</b>	<b>x, x</b>

Figure 1: State-Dependent Payoffs

## 2 The Model

### 2.1 Single-Cap Email Game with Automatic Messaging

Consider the following class of games indexed by  $x$  (the interpretation of  $x$  will be explained later). Two players  $i \in \{1, 2\}$  each chooses simultaneously from alternatives  $\{A, B\}$ . Nature moves first to select a state from  $\{a, b\}$  dictating which matrix game is to be played. With probability  $p$ , state  $b$  is selected, in which case  $G_b$  is played. With probability  $1 - p$ , state  $a$  is selected and  $G_a$  is played. The payoffs of each matrix game is shown in Figure 1, where the value of  $x(x \geq M)$  is common knowledge. The payoff uncertainty lies not in  $x$  but in the random state realization. The parameter restrictions are

$$p \in (0, \frac{1}{2}); L > M > 0 \tag{1}$$

Before the decisions, there exists a communication stage where an Email device help players spread information. The game features asymmetrically incomplete information in that player 1, the informed player, always observes the realized state; while player 2, the

uninformed player, does not. The device works as follows. If Nature draws state  $a$ , the device does nothing. If instead, state  $b$  is drawn, the device *automatically* sends a message on behalf of player 1 to player 2 revealing the state being  $b$ . However, this message gets lost on its way with a chance of  $\epsilon > 0$ , in which case player 2 won't receive anything. The message arrives with complementary chance  $1 - \epsilon$ . Denote player 2's information set as  $m \in \{0, 1\}$  indicating whether player 2 receives a message. It is assumed that  $m$  is player 2's private information, and hence player 1 cannot verify if the  $b$ -message arrives or not. These communication rules are common knowledge. As Rubinstein (1989) comments, the Email system is just an intuitive way of representing a broad class of communication protocols with noise.

Players make the payoff-relevant decisions after observing information obtained from the communication stage. Therefore, players' strategies are  $f_1 : \{a, b\} \rightarrow \{A, B\}$  and  $f_2 : \{0, 1\} \rightarrow \{A, B\}$ , respectively. This paper focuses on pure strategies.

## 2.2 Single-Cap Email Game with Voluntary Messaging

Following Binmore and Samuelson (2001), I consider a slight variant of the game above, where the only difference is player 1's active involvement in the communication stage. In this game, player 1 has to decide in state  $b$  whether to send the message revealing  $b$  to player 2, which is again subject to the  $\epsilon$  chance of getting lost. Sending the message costs player 1  $c \geq 0$  up front, which does not depend on if it arrives. Therefore, the message becomes *voluntary* and potentially costly. The device is still silent in state  $a$ , and the state-dependent payoffs are the same as in Figure 1. The payoff-relevant decision stage comes after the communication stage.

Denote player 1's messaging decision as  $\{S, NS\}$ , corresponding to send and not send. Then, player 1's pure strategy is the function  $f_1 : \{a, b\} \rightarrow \{S, NS\} \times \{A, B\}$ . Player 2's strategy is same as before,  $f_2 : \{0, 1\} \rightarrow \{A, B\}$ .

## 2.3 Rubinstein's Email Game

Absent of communication noise ( $\epsilon = 0$ ), players would have common knowledge about the selected state and hence which matrix game they are playing. That is, each player knows which game is played, each knows that the other knows which game is played, and so on, *ad infinitum*. The two games can then be analyzed separately. In  $G_a$ , both playing  $A$  is the weakly-dominant-strategy equilibrium. In  $G_b$ , both playing  $B$  is the payoff-dominant equilibrium, though both playing  $A$  is also an equilibrium (it's the risk dominant equilibrium if  $x > L$ ). Since players' interests are aligned, highlighting the coordinative nature of the problem, one would expect no issues for players to correctly coordinate on  $A$  in  $a$  and  $B$  in  $b$ , thereby achieving the efficient outcome. One caveat is that the player who chooses  $B$  alone would obtain the worst possible payoff (the penalty  $-L$ ) *irrespective of the state*. This makes  $B$  a risky option, whereas  $A$  is a safe option that guarantees a minimum payoff of 0.

Despite such riskiness, one would naturally conjecture that under a communication system with small noise  $\epsilon > 0$ , players would still be able to coordinate successfully on the efficient outcomes most of the time. However, Rubinstein (1989) shows this is not the case, when the system allows for too many informational exchanges. It turns out that this small and yet positive communication noise compounds with the strategic uncertainty inherent in the coordination problem, and leads to inefficiencies resulting from foregone opportunities of Pareto-improving joint risk-taking.

Rubinstein's Email Game has the same state-dependent payoffs as in Figure 1 with  $x = M$ , but has a slightly different communication device. In state  $b$ , the device automatically sends back-and-forth messages between players confirming receipt of the state- $b$  information, confirming that confirmation, and so on *ad infinitum*. Each message gets lost with probability  $\epsilon > 0$ . The communication stage ends when any message is lost, after which players observe their *own* number of messages sent (and received) and choose between  $A$  and  $B$ . Therefore, players could potentially have accumulated in their folder up to infinite amount of messages, with probabilities vanishing to 0. A player's pure strategy is  $f_i : \{0, 1, 2, \dots\} \rightarrow \{A, B\}$ .

A common frame of the Email system is from the distributed system literature: A soldier travels back and forth between two generals located apart, to spread the information that the enemy is weak, a knowledge only one commander knows at the beginning. During every trip, the soldier gets caught by the enemy with some small chance. The question is if they can ever set up a joint attack. Other frames of the game used in the literature include joint financial investment and revolting against a repressive government.

Rubinstein's Email technology essentially tries to bring players closer to common knowledge, because an extra message received means that another statement of the form "(players know that)<sup>k</sup> state is *b*" becomes true for some positive integer *k*, and common knowledge is defined by such statements being true for all *k*. Therefore, one should expect players to gain more confidence and therefore more likely to play the risky option *B*. If that's the case, a player's strategy would look like a threshold number of messages, above which they start to flip from *A* to *B*. Nevertheless, Rubinstein shows that the only sensible Bayesian Nash Equilibrium is that players always ignore the messages and play safe by choosing *A*, no matter how many messages they have sent and received. In this tacit equilibrium, communication is inefficient since players act as if deaf and messages never induce a change in action. Expected payoffs for both players are  $(1 - p)M$ , the same as if the Email device never existed.

The proof of this tacitness is through inducting on players' information sets, namely the number of messages received. The fact that *a* is the more likely state and that penalty *L* is larger than coordinative gain *M* implies that player 2's best response is to play *A* if seeing no message. From that onward, a pessimism ensures that playing *A* never becomes optimal. When a player stops hearing back from her partner, she cannot tell if it's her previous outgoing message that fails (in which case partner does not see that outgoing message), or it's her partner's confirmation to it that fails (in which case her partner sees it). A simple calculation on Bayes updating shows that she always assigns probability  $\frac{1}{2-\epsilon}$  to the former, pessimistic case, which is strictly above one half for any positive  $\epsilon$ . Given

the inductive hypothesis that her partner is playing  $A$  in the former case, it's best for her to play  $A$  too. Therefore, as players iteratively go into each other's mind and delete strictly dominated strategies (Spiegler, 2024), they forfeit themselves any chance of the more fruitful coordination in the opportunistic state. Higher-order rationality backfires.

Economists agree that communication often helps coordination, but now the question is how should players communicate? Rubinstein's result echos past literature on the importance of common knowledge in coordinative environments and raises challenging questions for communication protocol designers faced with noise – once common knowledge is missing in the beginning of the game, it's hard to rebuild it through a noisy protocol where messages can get lost (and it's hard for players to locate where exactly they were lost). Noise is destructive in a coordinative environment where players' higher-order beliefs are about the *other* player's belief about the state. Later theoretical articles tried to provide explanation for this paradox that players' behavior differ drastically under common knowledge ( $\epsilon = 0$ ) versus almost common knowledge ( $\epsilon > 0$ ) and issues with Rubinstein's Email protocol. Relaxing the notion of common knowledge to common belief, Monderer and Samet (1989) argue that the failure of the infinitely-bouncing Email protocol stems from its inability to generate an evidently public event that help players coordinate on joint risk-taking (sort of a strategy focal point). Chwe (1995) criticizes this protocol to be the worst precisely because it opens up the possibility of an unbounded amount of messages. Players' rationality requires them to always look for *another* confirmation before switching their action, which can never be fulfilled in an equilibrium. Binmore and Samuelson (2001) call this an "unending escalation" of message threshold through the angle of risk-sharing: both players want to be the "gatekeeper" themselves but their partner to take the risk alone of mis-coordination.

The other school of critiques argue that Rubinstein's tacit prediction is simply an artifact of theory but won't hold in reality – players will have enough confidence and act upon messages after a few rounds of mutual confirmations. In fact, Rubinstein himself remarks the tacit prediction as counterintuitive. Experimental evidence also show that people are not

very good at tasks like Bayesian inference, mathematical induction, and iterated elimination of strictly dominated strategies, all of which are key requirements in reaching Rubinstein's "weird Nash" result. Despite such dismissals, an unpublished experiment by Camerer et al (2003) shows great support for the tacit result. They adopted a strategy-method by asking participants for their intended actions upon receiving any number of messages, and then simulated real-time the messaging process for 500 independent rounds with random group pairing across rounds. This counted as one match, and they ran 14 matches in total with feedback after each match. The result was surprising – though  $B$  was chosen with some frequency at the first few matches, by match 13, *all* participants always choose the safe option  $A$ , corroborating Rubinstein's prediction. Before this result can be generalized, it remains to rule out other confounders like participant confusion and risk aversion, but whatever behavioral forces might be at play, the lesson is that a communication protocol that allows for rich amount of information flow can nevertheless be detrimental to coordination, especially when noise is inevitable.

## 2.4 Analysis of the Single-Cap Email Games

The Single-Cap variations of the Email Game essentially puts an artefactual bound on the message flow that exogenously truncates away further confirmations beyond the first message. The question here is, do players use and trust the first message, when they commonly understand it's the only message possible? The reason to restrict message amount to 1 is not arbitrary. An equilibrium where players act upon the first message is the most ex-ante efficient equilibrium (called the "utilitarian equilibrium" in Binmore and Samuelson, 2001). If the message cap is set instead at a higher amount (say, a cap of 5 means a guaranteed no confirmation beyond the fifth message in the system), there can be other equilibria where players require to receive more than one messages before flipping their action. These equilibria are less efficient because the longer chain of waiting decreases the probability of the Pareto-improving coordination. Moreover, picking this "flipping point"

message threshold is itself an implicit coordination for players, making equilibrium play of a certain type more challenging. The takeaway for protocol designers is a delicate balance between the richness and the effectiveness of information transmission.

It turns out that in theory, restricting to minimal information flow creates two types of equilibria for both automatic and voluntary messaging. One is the tacit equilibrium that mimics Rubinstein, where message is ignored by players. Under some conditions, there's also a continuum of vocal equilibria (the continuum is in voluntary models and comes from unbounded off-path beliefs) where message is utilized and interpreted in an efficient way. The following theorems summarize the Perfect Bayesian equilibrium (PBE) of each model and the associated parameter ranges.

**Theorem 1 PBE for *Single-Cap Email Game with Automatic Messaging***

(i) Consider the *Single-Cap Email Game with Automatic Messaging*. Under the minimal assumptions (1), there exists the tacit equilibrium where players always play  $A$ . That is,  $f_1(a) = f_1(b) = A$ ,  $f_2(0) = f_2(1) = A$ . The tacit equilibrium is ex-ante inefficient.

(ii) In addition to (1), if the following two conditions hold, the vocal equilibrium exists where player 1 acts upon the state and player 2 acts upon seeing the message. That is,  $f_1(a) = f_2(0) = A$ ,  $f_1(b) = f_2(1) = B$ .

$$x \geq \frac{\epsilon L}{1 - \epsilon} \tag{2}$$

$$x \leq \frac{(1 - p)(M + L)}{p\epsilon} \tag{3}$$

Beliefs (both on-path and off-path) and proofs are omitted here and given in the appendix. Several observations follow. First, other perverse equilibria exist, such as one where players always play  $B$ , which is the weakly dominated action for player 1 in  $a$ . They are ruled out from the discussion. Second, vocality exists for a narrower range of parameters. Equation (2) ensures a high enough temptation that when player 2 is responsive to the message,

it's optimal for player 1 to play  $B$  in  $b$  even without hearing back (which is impossible under the cap). Fixing  $x$ , (2) can also be written as an upper bound on the noise  $\epsilon$  for the message to be sufficiently trustworthy in conveying the state. Equation (3) ensures temptation is not too high to induce player 2 to blindly play  $B$  even when not receiving the message.

Solution to the voluntary has similar structure but with a more stringent parameter requirement for the existence of vocality, and a slight adjustment to account for the small message cost.

**Theorem 2 PBE for *Single-Cap Email Game with Voluntary Messaging***

(i) Consider the *Single-Cap Email Game with Voluntary Messaging*. Under (1), there exists a continuum of tacit equilibria with strategy profile distinguished by off-path beliefs, where players disregard the state or message status, and always play  $A$ . In terms of messaging decision, if  $c = 0$ , player 1 chooses  $S$  or  $NS$ . If  $c > 0$ , player 1 chooses  $NS$ .

(ii) In addition to (1), if the following two conditions hold, there exists a vocal equilibrium where player 1 sends the message and plays  $B$  when seeing  $b$ , and player 2 acts upon receiving the message. That is,  $f_1(a) = NS, A$ ;  $f_1(b) = S, B$ ;  $f_2(0) = A$ ;  $f_2(1) = B$ .

$$x \geq \frac{\epsilon L + c}{1 - \epsilon} \tag{4}$$

$$x \leq \frac{1 - p}{p}(M + L) \tag{5}$$

The tacit equilibrium that mimics Rubinstein's again persists. When message is free ( $c = 0$ ), given that player 2's action is not responsive to the message and hence it is useless anyway, player 1 is indifferent between sending and not sending. Instead, when message is costly ( $c > 0$ ), player 1 would not send it. The extra conditions for the existence of vocality vary slightly compared to these in the automatic model. Equation (5) is a direct counterpart of (2) taking into account the message cost. On the other hand, equation (6) represents a *tighter* upper bound than in (4) and does not involve the cost (this bound is exactly  $\epsilon$  times

the previous bound). This upper bound on temptation ensures that player 2 would play  $A$  when seeing no message, if player 1 chooses  $B$  without sending the message. This prevents a type of perverse equilibrium where player 1 does not send the message and both players choose  $B$ .

Therefore, the difference in the upper bound of temptation between the automatic and the voluntary protocols reflects a difference in players' outside option. When message is automatic, players are forced to be involved in the messaging system as there's always a chance of message shooting out and appearing. The only question left is how players interpret the message. In contrast, when message is voluntary, players (effectively, player 1) have the outside option of abandoning the system altogether, so an extra participation constraint should be in place to rule out the outside option, in favor of vocality where the system is actively deployed. This difference in participation enforcement might explain the design of auto-reply in various communication systems empirically observed, when the goal is to minimize drop-out.

## 3 Experimental Design

### 3.1 Treatments and Parameters

The goal of the experiment is to test equilibrium selection in the lab when theory is indecisive between tacitness and vocality, and find the protocol-parameter configuration that generates the most instances of vocal behavior and hence highest efficiency. I adopt a  $3 \times 3$  design where I vary the feature of how players are allowed to communicate in one dimension, and the temptation of risk-taking through  $x$  in the other dimension. Table 1 shows the number of participants for each configuration, where *Low*, *Medium*, *High* corresponds to  $x = 1, 2, 4$ , respectively. Under each  $x$  value, the communication protocol can take one of the three forms that closely follow the theories in the previous section. In *Automatic*, players do not have control over either the sending or the receiving of the state- $b$  message. In *Voluntary-*

*Free*, player 1 in state  $b$  chooses in the communication stage whether to send the message, an action that is unobserved by player 2, and such message is free for the sender ( $c = 0$ ). Lastly, the *Voluntary-Costly* treatments has the same setting as *Voluntary-Free* except that player 1 bears the cost ( $c = 0.5$ , and the presence of such cost is common knowledge) if she chooses to send the message.

**Table 1: Number of Participants by Configuration**

protocol/temptation	<i>Low</i>	<i>Medium</i>	<i>High</i>
<i>Automatic</i>	20	24	22
<i>Voluntary-Costly</i>	( $\nexists$ vocal)	20	10
<i>Voluntary-Free</i>	10	10	

Other than the temptation  $x \in \{1, 2, 4\}$  and message cost  $c \in \{0, 0.5\}$  that differ across treatments, the following parameters stay the same for all treatments.

$$p = 0.4, M = 1, L = 2, \epsilon = 0.3$$

are, respectively, prior of the opportunistic state  $b$ , reward for correct coordination on  $A$  in state  $a$ , and the message-drop probability. This set of parameters satisfies the inequalities (2)-(5) to ensure existence of both types of equilibria for the non-empty cells in Table 1. In particular,  $x$  must be in the range  $[0.86, 4.5]$  when  $c = 0$ , and  $[1.57, 4.5]$  when  $c = 0.5$ . The *Voluntary-Costly-Low* cell is blank because vocality does not exist. The *Voluntary-Free-High* cell is blank because the result is expected to resemble its costly counterpart (explained later). In the experimental games, all payoffs are increased by 2 points to avoid actual losses (and loss aversion that might be induced), so the worst outcome then becomes 0 points, and the temptation reward becomes 3, 4, and 6 points, for *Low*, *Medium*, and *High*, respectively. The noise parameter was chosen to be away from 0 so that participants take the message-drop friction seriously.

## 3.2 Hypotheses

The core policy question in this paper is to figure out the most effective communication protocol in inducing players' vocal behavior, which is the most (ex-ante) efficient equilibrium outcome given the constraint that players face communication noise. Therefore, the central performance measure of a protocol is the prominence of vocal strategy players use instead of the tacit strategy. Call this measure of vocality  $v$ , where

$$v_{kx} \equiv \hat{Pr}(B|b \text{ or } m = 1), \quad k \in \{A, VF, VC\}, x \in \{L, M, H\}$$

denotes, for a given configuration with protocol  $k$  and temptation  $x$ , the empirical fraction of instances that players flip their action from the safe option  $A$  to the risky option  $B$  upon receiving positive news in the communication stage (state  $b$  for player 1 and the message for player 2), pooled over the two roles. Since vocal and tacit equilibrium differ in their prediction of behavior exactly at these two information sets,  $1 - v$  measures the fraction of  $A$ -play in these information sets and hence the prominence of tacitness. Under the random re-matching of participant pairs across rounds, it makes sense to look at individual player strategies rather than the actual coordination success/failure of specific groups in the experiment.

For a given protocol, vocality should respond to changes in incentives captured by the temptation  $x$ , which essentially measures the basin of attraction of the vocal equilibrium. Therefore, we should expect vocality to increase as we move across columns of Table 1 from left to right, within each row. In the context of equilibrium selection, this exercise serves as a sanity check that both types of equilibria can be observed in the lab, without one clearly outracing the other. The necessity of a lab experiment stems from the mixed theoretical results in refinement literature of the Email Game.<sup>1</sup> This leads us to the first hypothesis.

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<sup>1</sup>For example, in an Email game with no message cap but voluntary and costly messaging, evolutionary stability selects a wide range of vocal equilibria (Binmore and Samuelson, 2001); in a re-framed and slightly varied version of the original game, only the tacit equilibrium survives two ad-hoc refinement rules (ex-post efficiency and immunity to strategic uncertainty) (Morris, 2001).

**Hypothesis 1**  $v_{kL} < v_{kM} < v_{kH}$  for  $k \in \{A, VF, VC\}$  whenever comparable

The more interesting question is, fixing the payoff structure, how different rules by which decision-relevant information is disseminated among players affect their behavior through shaping their interpretation of these information. A natural conjecture is that for a given temptation level, message is more effective at conveying information and inducing behavior change in the *Voluntary* treatments than the *Automatic* treatments. The reason is that the added "voluntariness" should in principle make messages more trustworthy by signaling the sender's coordinative intent. Furthermore, this signaling effect should be even stronger in the *Costly* treatment than the *Free* treatment, due to the sender's sunk cost on the message. A player 1 who were to pick *A* anyway would not bother investing in this sunk cost in the first place. Therefore, player 2 should be more assured of player 1 picking *B* when receiving the message (which means that player 1 has chosen to send it), and hence should be more assured of picking *B* herself. Player 1 understands this logic and therefore is happy to bear the cost and send it, which constitutes the vocal equilibrium. In that sense, the voluntary and costly message makes equilibrium selection more clear-cut. This leads to the second hypothesis.

**Hypothesis 2**  $v_{VCx} > v_{VFx} > v_{Ax}$  for  $x \in \{L, M, H\}$  whenever comparable

### 3.3 Procedure

The experiment was approved by UVA Institutional Review Board for Social and Behavioral Sciences (IRB-SBS-7602). I programmed the experiment in oTree (Chen et al, 2016) and ran 11 lab sessions at the Veconlab at the University of Virginia between June and September 2025. Each session lasted about 45 minutes and enrolled 10-12 participants, with a total of  $N = 116$  participants aggregated across sessions. The design is between-subjects: in a given session, all participants played 15 rounds of the Single-Cap Email Game under one protocol-temptation configuration ("treatment"). Roles were denoted "Informed" for player

## Decision Stage (Round 1)

In this round, you are the **Uninformed** participant.

You have received a message from the other participant saying "●".

Now, please make your choice.

Action

A  B

Next

**Matching and Earnings:** Random group pairing for each round. Your performance in one random round determines your earnings.

**Chance of Situation:** ▲ --60%; ● --40%. Generated randomly and independently for each round.

**Role:** Only the **Informed** participant knows the realized situation, while **Uninformed** does not.

**Situation-Dependent Payoffs:** represented by Situation-Payoff Matrices

Payoff Matrix under ▲  
(**Informed**, **Uninformed**)

▲	Uninformed		
	A	B	
Informed	A	3, 3	2, 0
	B	0, 2	2, 2

Payoff Matrix under ●  
(**Informed**, **Uninformed**)

●	Uninformed		
	A	B	
Informed	A	2, 2	2, 0
	B	0, 2	3, 3

**Automatic Messaging System:**

- In situation ●, sends message "●" to **Uninformed**. But message gets **lost** with a chance of **30%**, in which case **Uninformed** won't receive anything.
- Does nothing in situation ▲

Figure 2: Decision screen for Player 2 in *Automatic-Low*

1 and "Uninformed" for player 2, randomly assigned at the start of the sessions and fixed throughout. In each round, participants of opposite roles were randomly re-matched in pairs. After the 15 rounds, one round was randomly selected for payment. Exchange rates were calibrated so that, across temptation  $x$ , the Email Game earnings range was aligned between \$0 and \$12. The realized payoff from the selected round was converted at the treatment's exchange rate. Participants then completed ten Holt-Laury (HL, 2002) binary lottery choices with  $2\times$  the baseline payoff scale of theirs. One HL row was drawn at random for payment. All participants received a \$10 show-up fee. Average total earnings (game + HL + show-up) were \$25, paid privately in cash at the end of the sessions.

At the start of each session, the experimenter read standardized instructions covering priors over states, state-contingent payoffs, and the messaging device (emphasizing the fact that a message might get lost on its way with a chance of 30%). To avoid framing the state-action mapping, we labeled state  $a$  as "situation  $\triangle$ " (triangle) and state  $b$  as "situation  $\circ$ " (circle), but keep actions as  $A$  and  $B$ . Participants had to correctly answer three comprehension questions before proceeding, with unlimited attempts. A concise instruction summary remained visible on all decision screens. At the end of each round, participants received feedback on the realized situation, their own choices, and the resulting payoff of that round. Figure 2 provides the informed player 2's decision screen with instruction summary, for the *Automatic-Low* treatment. More detailed instructions and decision screens can be found in Appendix B.

## 4 Results

### 4.1 Effect of Temptation on Vocality

Both types of equilibria emerge in the lab and respond to changes in incentives. Figure 3 shows the mean fraction of vocal behavior  $v$  for each communication protocol in blocks distinguished by temptation level, where  $v$  is defined as the percentage of instances that

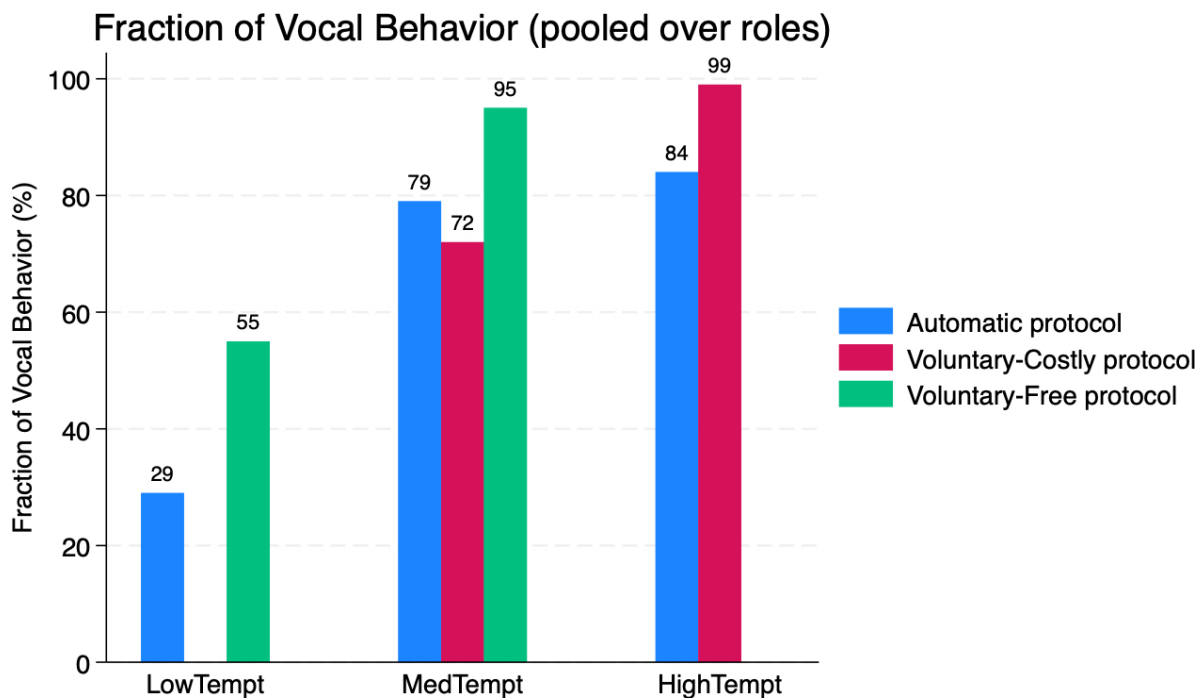


Figure 3: Prominence of Vocality

player 1 (2) chooses  $B$  when seeing state  $b$  (the message), pooled over the two roles. All bars have height bounded away from 0, and even in the most stringent payoff environment against vocal behavior when  $x = 3$  ( $x$  must be above 2.86 in the experimental game for the existence of the vocal equilibrium), vocality reaches 29% in the *Automatic – Low* treatment.

For each protocol, vocality increases as the potential gain from joint risk-taking increases. This increase in vocality is especially obvious from low to medium temptation (29% vs. 79% for the *Automatic* protocol and 55% vs. 95% for the *Voluntary-Free* protocol). This is expected since the reward to both players of a correct but risky coordination ( $B, B$ ) is "at the margin" and equal to that of a correct and safe coordination ( $A, A$ ), and therefore the strategic uncertainty of choosing  $B$  is the highest. Relaxing this temptation reward from 3 to 4 points releases this strategic tension and makes the risky option more worthwhile trying.

The increase in vocality from *Medium* to *High* temptation, though temptation reward increases by 2 payoff points (from 4 to 6), is less dramatic. With no surprise, the highest

vocality is obtained when temptation is *High*. In the *High* block, I did not run treatment on the *Voluntary-Free* protocol whose vocality is expected to be at least as high as that of *Voluntary-Costly*, given that this relationship holds in the *Medium* temptation block (a point to be discussed below).

## 4.2 Mechanism of Credibility: Voluntariness vs. Sunk Cost

What makes a message credible in the sense of effectively conveying players' intent of joint risk-taking? Clearly, different rules of communication induce different interpretation of a message when it arises, affecting players' beliefs about opponents' and in turn their own coordinative behavior. Figure 3 shows the performance of each protocol, fixing the level of temptation. Under *Low* and *High* temptation, the *Voluntary* protocol has higher rate of vocal behavior than the *Automatic* protocol. However, Hypothesis 2 fails under *Medium* temptation in the middle block, the only block where data for all protocols are available – the *Voluntary-Costly* protocol does worst, rather than best, among all three protocols, even worse than *Automatic*. The part that aligns with prediction is the superior performance of *Voluntary-Free* over *Automatic*. The conclusion is that for a given level of temptation, allowing messaging to be a voluntary decision (combining cases of both free and costly messaging) induces more coordinative risk-taking of participants, but this improvement is solely driven by the voluntariness rather than the sunk message cost.

Is a costly message more convincing than a free message? Yes, though to a limited extent. Indeed, receivers (player 2) are more willing to act upon seeing the message when they understand the sender has paid a sunk cost for it than when it is free. That is, *conditional on player 1 choosing to send the message*, vocality is higher. This can be done by comparing receiver's vocality  $\hat{Pr}(f_2 = B|m = 1)$  between *Voluntary-Costly-Medium* and the *Voluntary-Free-Medium*, which is slightly higher in the *Costly* environment (data not shown here). The intuition is that a sender who were to play the safe option *A* should not have chosen to incur the cost to send the message in the first place. Therefore, receiving the message

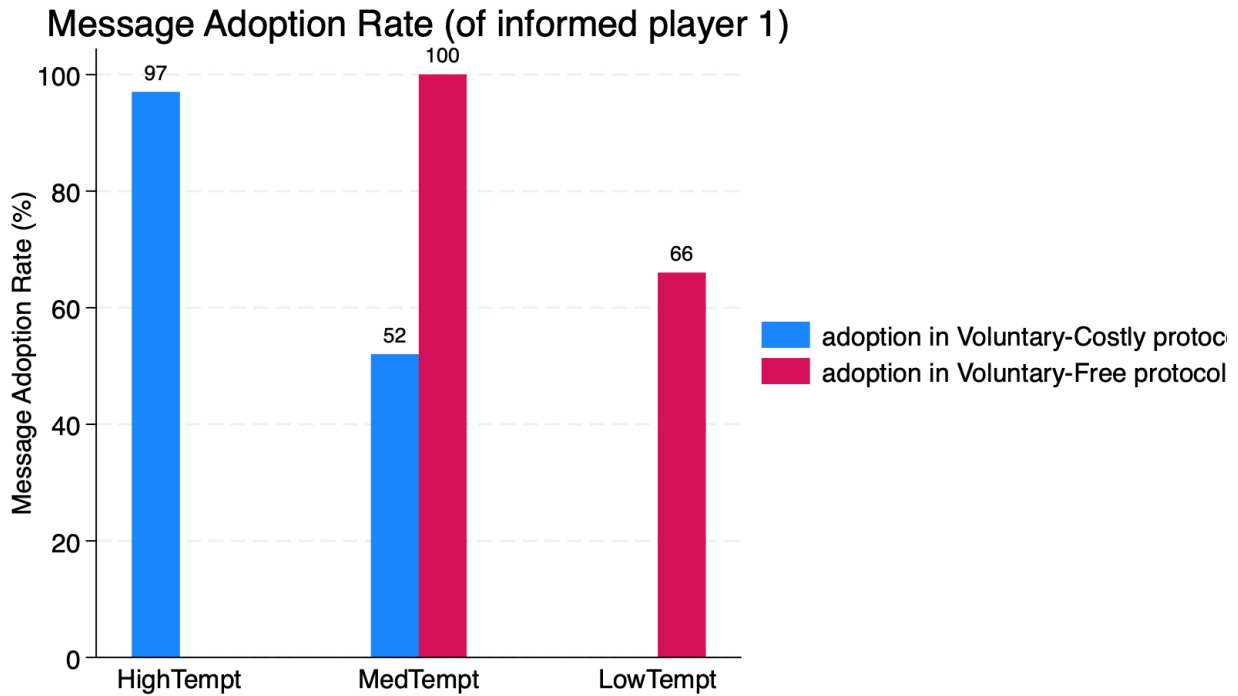


Figure 4: Message Adoption Rate

should greatly reduce player 2's strategic uncertainty. Anticipating this, and given that the message is sufficiently likely to reach its destination (Equation (4) expressed in terms of  $\epsilon$ ), player 1 has an incentive to initiate this equilibrium selection through investing sunk cost in "purchasing" the signal. This is essentially the logic behind the vocal equilibrium under costly voluntary messaging.

If a costly message manages to signal a stronger intent of coordinative action, why is vocality unexpectedly low? It turns out that the cost deters the sender from sending the message in the beginning! Figure 4 depicts the average message adoption rate in each *Voluntary* treatment, defined as the fraction of instances that player 1 chooses *Send* whenever they face such a choice (i.e. when state is  $b$ ),  $\hat{Pr}_1(S|b)$ . The *Medium* block shows that *all* informed players adopt the messaging system when it's free, whereas only about half do when it's costly. People back out from investing in the sunk cost when strategic uncertainty is relatively high, i.e. when they are unsure if the opponent will trust and listen to the message.

A simple calculation can demonstrate how this strategic uncertainty might lead player 1 to back out. Again take the *Medium* temptation level as an example, and message costs 0.5. Suppose player 1 believes player 2 will surely act upon the message, that is,  $\sigma_2(B|m = 1) = 1$ ; but plays safe if not seeing the message,  $\sigma_2(B|m = 0) = 0$ . Then, player 1's expected payoff for sending the costly message is,  $\pi_1(S) = 0.7 \times 4 + 0.3 \times 0 - 0.5 = 2.3$ . If not sending, player 1 just gets the sure safe payoff without incurring the cost,  $\pi_1(NS) = 2$ . If player 1 trusts player 2 to be fully reactive to the message, sending it would benefit. However, suppose player 1 assigns an agnostic belief on player 2's responsiveness,  $\sigma_2(B|m = 1) = 0.5$ . Then,  $\pi'_1(S) = 0.7 \times 0.5 \times 4 + 0.7 \times 0.5 \times 0 + 0.3 \times 0 - 0.5 = 0.9 < 2 = \pi_1(NS)$ , which means not sending is the risk dominant strategy that is more robust to strategic uncertainty under this payoff and noise structure. For the sender, the receiver's unresponsiveness essentially acts in the same way as the noise, diluting the chance of the opportunistic gain from risky coordination. When such gain is not very high (here, 4) or when the message system is not that reliable, it's in player 1's best interest to abstain from the system and give up the chance of the Pareto improvement.

These double-edge effects of sunk message cost highlight a trade-off for communication system designers. On the intensive margin, a costly and voluntary message carries a more sincere intent of coordination of the sender and (endogenously) improves the quality of the underlying information transmission process. On the extensive margin, however, a more pricey protocol discourages senders' adoption when they bear both the signal cost and the risk of mis-coordination resulting from the uncertain belief of the receivers' behavior. The initial data here show that the negative effect of cost on adoption dominates in the lab, driving vocality low (and even overturning the advantage of *Voluntary* over *Automatic*). In contrary, a voluntary but free messaging environment boosts up message adoption without hurting message efficacy in inducing receivers' behavior change, performing best among all three types of protocols. A remaining puzzle in the data is the low message adoption when it's free but temptation is low.

Given the artifact of the lab and limited amount of data so far, caution should be taken against dwarfing the role of sunk cost in equilibrium selection in more general strategic environments. This paper does not take a stance on what is the deeper mechanism behind voluntariness. Further work should unpack the exact causal channel of how voluntariness contributes to tilting equilibrium selection towards the vocal. It might be that the main information carrier is still cost, just not an explicit cost. For example, if player 2 thinks it takes some tiny effort or mental cost for player 1 to click the "send" button, and if player 1 understands that, an economically free message can still do its job. At least the current result cannot rule out the interpretation of voluntariness as some sort of commonly-understood cost. The core determinant of coordination seems then to be an implicit common ground between the sender and the receiver of what a message means, but what the meaning actually is of marginal importance. This arbitrariness in message interpretation highlights the subtlety and fragility of equilibrium selection in coordination games under the presence of both mechanical and strategic uncertainty. This echoes theoretical and empirical studies on bank run a la Diamond and Dybvig (1983) showing that selection into the bad (bank run) equilibrium instead of the good equilibrium can depend on non-fundamentals totally unrelated to performances of the bank or the economy, such as "confidence". The Macroeconomics literature calls these type of equilibria driven by random extrinsic variables as "sunspot" equilibria.

### **4.3 Forward Induction and Cheap Talk**

The superior performance of voluntary over automatic messaging in inducing systematic behavior change echos the long-standing idea that a player's earlier choice can affect equilibrium selection in the later subgame through shaping players' beliefs in a certain direction. These pre-game moves can be either a payoff-irrelevant and non-binding communication, such as in cheap talk models, or a material commitment such as money-burning, advertising, and rejecting an outside option, such as in forward induction. The logic is that under some

conditions these moves credibly signal the signal sender's intended action in the upcoming subgame, thereby affecting the follower's best response and result of the game. Importantly, how well forward induction and cheap talk can predict equilibrium selection depends heavily on the underlying incentive structure of the games.

One type of games with multiple equilibria feature conflicts of interests between players across these equilibria. In a  $2 \times 2$  Battle-of-Sexes game (BoS), Van Damme (1989) shows that when one of the two players gives up an outside option with payoff between what she can get in her preferred equilibrium and that in her least preferred equilibrium in the later BoS subgame, and the other player observes this move, then the first mover's preferred equilibrium must be selected in the subgame. The forward induction logic is that by giving up the outside option, the first mover is implicitly sending a message to her partner that she has committed for her preferred action. Understanding this message, the partner will best respond by coordinating. Cooper et al (1993) test this BoS with outside option in the lab but find limited evidence of forward induction. Instead, they find strong effect of 1-way cheap talk, where one player can announce to the other player her intended action before actual choices, in inducing the announcer's preferred equilibrium outcome. The message there serves as a credible threat. In another treatment where the sender's announcement is never received (but both players understand the asymmetric role caused by the sender having this message tool), the favoring effect becomes much weaker, implying that the message does contain valuable information and should be actually materialized to persuade beliefs. My lab results corroborate this argument, as the receivers flip their action only when they indeed see a message. Interestingly, they also find that 2-way cheap talk does not tilt equilibrium selection in any direction, where threats from the two sides essentially cancel each other out.

Another type of games have Pareto-ranked equilibria, so players' interest are perfectly aligned as for which equilibrium outcome they jointly prefer. The Email Game and my variations fall into this category of coordination games, with another distinctive feature being the presence of a safe action (action  $A$ ). Cooper et al (1992a) test experimentally

a  $2 \times 2$  coordination game with complete information and a safe action, and find that 2-way communication where both parties can announce intended actions works best, while 1-way communication does not always do better than no-communication. The argument is intuitive – when the issue of coordination is to resolve strategic uncertainty and build trust, mutual confirmation is necessary. My results shows that letting one player "talk" to the other without hearing back, nevertheless, conveys information efficiently in a similar setting under incomplete information, despite the highly structured and restrictive nature of the Email system in my model. They have similar findings in a follow-up paper (Cooper et al, 1992b) that in a coordinative environment 2-way communication works much better than either 1-way communication or the self-commitment message signified by a player's rejection of the outside option.

Despite the appealing descriptive power of forward induction as an equilibrium refinement tool, it's important to distinguish it in the lab from other confounds such as dominance of strategy (Brandts and Holt, 1994)<sup>2</sup> and focal point (Cooper et al, 1993). To reach a more robust conclusion about the role of sunk cost in information conveyance requires more data on the existing treatments and further variations on both the message cost and the communication noise parameters. See Baliga and Morris (2002) for a theoretical micro-foundation of credibility of messages general cheap talk games. In short, "messages are believed if it is in the interest of the sender to follow through *should his message be believed* [by the receiver]" (Cooper et al, 1992b).

**Summary** As predicted by Hypothesis 2, *Voluntary* protocols where messages convey information on both the state and players' intended action result in a higher percentage of vocal behavior in the lab than *Automatic* protocols that only disseminate information on the state. Contrary to initial prediction, however, the *Voluntary-Free* protocol performs better than its costly counterpart. The implication is that the voluntariness of the message

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<sup>2</sup>One technical point is that in their game of Battle-of-Sexes with one player having an initial outside option, the other player cannot observe this player's choice of accepting/rejecting the outside option. They argue that this environment is even more favorable to forward induction than the case where BoS is a proper subgame as in Cooper et al (1993). See footnotes 1 and 2 in Brandts and Holt (1994).

on its own carries the information content by signaling coordinative intent. This efficient conveyance of information leads to higher frequency of coordinative behavior. On the other hand, adding a sunk message cost to the sender (on top of the voluntariness) does not significantly make the message more trustworthy, but instead hurts senders' message adoption in the first place and hence leads to lower coordinative efficiency. These results are consistent with the literature on cheap talk and forward induction, where players' past moves, even if sometimes inconsequential for payoffs, can serve as signals of intended action and affect equilibrium selection in the later subgame. A new angle to forward induction theories is that in a coordinative environment with perfectly aligned interests, effective information transmission needs not rely on cost-burning alone. The voluntariness contained in a cheap-talk message that reveals intention does well in resolving strategic uncertainty and directing players to the more efficient outcome.

## 5 Conclusion

This paper investigates how rules of communication in a coordination game under incomplete information affect coordinative efficiency through shaping players' interpretation of the communication process. To achieve the Pareto-optimal outcome, players have to correctly utilize the messaging protocol to overcome coordinative difficulties caused by both strategic uncertainty and communication noise. While Rubinstein's original protocol allows for rich information flow in the form of back-and-forth confirmations between players, I consider a restrictive information exchange process where at most one message can be sent. This artefactual message cap generates interesting equilibrium selection problem to be tested in a lab experiment.

In the experiment, I compare players' coordinative efficiency for each incentive structure under different communication protocols – one where players have no control over the message; another where sender has to voluntarily incur a sunk cost to send the message; the last

where this voluntary sending is free of cost. As expected, voluntary communication usually performs better than the automatic counterpart because a voluntary message conveys not only information about the state but also the sender's intended action, thereby reducing strategic uncertainty. Contrary to initial conjecture, nonetheless, the sunk message cost induces half of the senders to abandon the protocol and players cower back to the safe option, generating low coordinative efficiency for the *Voluntary-Costly* protocol. On the other hand, the *Voluntary-Free* protocol benefits from universal message adoption without a significant drop in message credibility, and therefore achieves the highest coordinative efficiency.

These results imply that when players' interests are perfectly aligned, effective conveyance of coordinative intention does not have to rely on cost-burning. The results speak to the literature on forward induction and cheap talk where history of play affects strategic evolvment in the later subgame. However, distinguishing the exact channel through which message shapes belief formation requires further experimental variation on the cost and reliability of the messaging protocol, before policy implications can be derived. Moreover, adherence to vocal behavior might be different for the sender than the receiver in the voluntary protocols. Some casual observation (data not presented here) shows that senders seem to bear more cognitive burden as they are the initiators of the game making the extra messaging decision and therefore have to take the receiver's problem into account. There's evidence of senders' interim inconsistency where they send the costly message in the hope of persuading for the joint gain, but back out in the end by choosing the safe option, likely out of fear for the message-loss and/or the receiver's inaction. On the other hand, receivers almost always act upon the message no matter if the message is backed by the cost or not.

The experiment and theory in the paper can be extended in multiple ways to derive broader strategic implications of how players communicate to each other under technical constraints (noise, limited content, limited reply, etc.). First, the game can be generalized to more than two players where each player knows partially the truth and tries to convey information to the entire group to facilitate a joint action. What is the best way to dissemi-

nate information? Should there be a central mediator that talks to everyone independently? Or should players talk to each other sequentially to aggregate knowledge gradually? Chwe (1995) considers such optimal communication network for 3 players in a coordinated-attack problem. Second, relaxing the message cap to be some finite number larger than one would shed light on why coordination should fail (or not) in Rubinstein's infinite-bouncing protocol. For example, it would be nice to see if a higher cap in the automatic protocol results in lower vocality, and if so, whether it's due to players' inability to implicitly agree on "how many messages received are enough for action", or due to subject confusion and behavioral noise. Tracing out this comparative statics in the cap can help answer the ultimate comparison between a simple and clear protocol versus an informational-rich but potentially confusing protocol in terms of building coordinative confidence among players. Replicating Camerer et al (2003) would also be an exciting exercise. The last line of extension aims to approach real communication processes, such as adding a potentially noisy verification on message arrival for the sender (e.g. the "delivered" icon next to a text message).

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