A Road to Efficiency through Communication and Commitment*

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Abstract

We experimentally examine the efficacy of a novel pre-play institution introduced by Calcagno et al. (2014) in a well-known coordination game—the minimum-effort game—in which coordination failures are a robust and persistent phenomenon. This new institution allows agents to communicate while incrementally committing to their words, leading to a sharp theoretical prediction: the efficient outcome is uniquely selected in the extended coordination game. Commitment-enhanced communication significantly increases subjects' payoffs, and achieves efficiency levels considerably higher than non-binding communication. We document that commitment alters communication, and that subjects behave in a forward-thinking and myopically suboptimal manner at the beginning of their interaction and then myopically best respond as the deadline looms.

JEL Classification: C73, C92, P41; **Keywords:** Coordination , Revision Games, Dynamic Games, Continuous-time experiments.

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1 Introduction

Economic situations often require agents to coordinate their actions, and coordination failures leading to underperformance are pervasive in society. Coordination environments present players with particular strategic tradeoffs: achieving better outcomes requires players to choose an action that they are typically unwilling to take unless other players take the same action. Although players in these environments prefer the same outcome, strategic uncertainty leads to coordination failures. The literature seeking to identify institutions to overcome coordination failures uses controlled experimental environments to compare interactions under different institutions.

Given that players' interests are aligned in coordination games, and that uncertainty is the root of failure, institutions formalizing communication have been a natural starting point for attempted solutions to the problem. However, experimental evidence on the effects of communication is mixed, and communication alone may not be enough to ensure success, even in a controlled experimental setting.[1] Additionally, many of the studied pre-play interactions lack theoretical implications; therefore, even if a given intervention empirically improves coordination in the lab, it is unclear how to isolate the features that are responsible for its success.

In this paper, we experimentally examine a novel institution studied theoretically by Calcagno et al. (2014)—asynchronous revision pre-play—which predicts that the Pareto efficient profile is the unique outcome in an extended coordination game. In addition to the uniqueness result regarding the outcome, the theory is used to obtain testable predictions of agents' dynamic behavior throughout the pre-play phase. The institution in Calcagno et al. (2014) formalizes a simple intuition: agents must prepare the actions that they intend to take at a predetermined deadline. The institution augments the coordination game with continuous-time pre-play interaction, in which players prepare their actions. As the deadline approaches, each player receives opportunities to update her prepared action, at asynchronous and stochastically determined times. At the deadline, the players take their most

[1] Some communication protocols, such as two-way communication or public announcements, have been documented to increase coordination (see, e.g., Cooper et al. (1992), Chaudhuri et al. (2009), Charness (2000), Blume and Ortmann (2007), and Burton and Sefton (2004)). However, other protocols, such as one-way communication or private advice, have led to coordination failures (see Cooper et al. (1992) and Chaudhuri et al. (2009)).

recently prepared actions, and their payoffs are determined only by these actions. Intuitively, the preparation phase allows players to communicate their intentions while incrementally committing to them. Formally, the action that a player chooses at any point in time may become her final choice, with some strictly positive probability. Furthermore, the closer the deadline gets, the higher that probability becomes. Consequently, communication in the pre-play phase is never cheap talk, and, as the clock ticks, players become gradually more committed to their prepared actions.

In the lab, we embed the mechanism into a minimum-effort game, in which a player's payoff depends on her own effort choice and the minimum effort chosen by the members of her group. We focus on this game because it is a central example of a coordination game with multiple Pareto-ranked equilibria and because a vast experimental literature observes coordination failures in this environment. In this paper, we test whether a previously untested mechanism—asynchronous revision pre-play—can reduce coordination failures and allow those involved to reach higher payoffs. To bring this institution to the lab, we extend its theoretical results in two directions, highlighting that some of the original assumptions are not key for the main findings to hold. First, we introduce discrete instead of continuous time in the pre-play phase. Second, we adapt non-independent random revision opportunities, maintaining the asynchronicity of the revisions. Our experimental design replicates the conditions of the theoretical setup.

In the main treatment, *revision mechanism*, the pre-play phase starts with all group members choosing an initial effort, which, if an opportunity arises, they can update during a preparation phase of 60 seconds. Revision opportunities are awarded randomly to each group member, and the probability of two group members revising in the same instant is zero. In a single dynamic graph, each player can see real-time information on all group members' posted effort choices, including the history of posted choices, revision opportunities, and updates. Players can change their effort on their screen at any time (that is, change their intention). Still, these revisions will not be publicly posted unless the players are awarded a revision opportunity. Throughout the 60-second preparation phase, each player is expected to be offered eight revision opportunities. At the end of the pre-play phase, the players take the most recently revised actions, and those are the only payoff-relevant effort choices.

Our first main result is that the mechanism increases efficiency by more than 65% compare to the case without any pre-play communication. The efficiency gains achieved with the revision mechanism (efficiency is 80%) are significant when compared not only to the baseline simultaneous game (48%) but also to the standard in the literature, one round of public cheap-talk messages (64%). In addition to establishing the effectiveness of the overall mechanism to aid coordination, we examine three additional treatments to test the robustness of the main result and to provide insights into the features that are necessary for its success. In particular, we are interested in understanding how communication and commitment interact to improve coordination, and also in documenting that the theoretically identified forces drive the observed benefits. To that end, we examine three additional treatments.

The revision mechanism departs from the standard cheap-talk mechanism implemented in the literature in two ways: it improves players' capacity to communicate by offering a rich multi-round communication protocol, and it forces players to commit to their words gradually as the deadline approaches. In the treatment we refer to as *revision-cheap-talk*, we endow the players with a communication protocol just as rich as the revision mechanism, but with no commitment (that is, the last-instant prepared choice is not binding). This treatment leads to efficiency gains that are statistically indistinguishable from the gains of standard cheap-talk communication. These results inform us that the success of the revision mechanism is not only due to the richness of multi-round communication, but that commitment also plays a crucial role. Furthermore, the manner of communication is affected by commitment. In the presence of commitment, players are more likely to believe what others communicate, and they communicate in a more parsimonious way, especially when there is little time left before the deadline.

To test the relevance of *gradual* commitment, we design a treatment in which we increase how abruptly players commit to the degree at which the theoretically anticipated results fail. In this treatment, referred to as *infrequent-revision mechanism*, revision opportunities are awarded very infrequently. Because of the low probability of revision opportunities, this treatment does not satisfy the conditions for the theoretical results to hold, and, thus, we use it to directly test the condition of the theorem. Subjects' behavior in this treatment is similar to that in the cheap-talk treatments, with statistically indistinguishable payoffs that are significantly lower than those of the revision mechanism. These results demonstrate that the gradual nature of the commitment is an essential factor. It allows players to use the early moments of the pre-play phase to communicate their intentions and, thus, coordinate on more efficient outcomes.

The final treatment elucidates the subjects' dynamic behavior during the pre-play phase. In the main treatment, 86% of initial choices were the efficient choice of effort. With such small variation in the initial decisions, it is difficult to observe how participants would alter their choices dynamically in response to various strategic scenarios. Therefore, we consider a treatment that we call the *random-revision mechanism*, which is similar to the revision mechanism, except that subjects' initial choices are picked for them at random. Theoretically, this modified environment should lead to the same subject behavior and not affect the efficiency result. Indeed, the efficiency levels are statistically and economically indistinguishable (78% vs. 80%). The randomization of the initial choices, however, provides us with enough initial variation in behavior to analyze subjects' dynamic best response patterns. When far from the deadline, subjects revise their choices in a forward-thinking way, revising to higher effort levels, even though doing so could harm their payoff if others do not revise. However, as the deadline looms, subjects revise their effort choices towards the minimum effort of their group. This behavior indicates that subjects understand the potential for early communication to lead to more coordination, but as the deadline approaches, they focus on maximizing their payoffs based on the current strategic configuration.

The pre-play revision mechanism experimentally studied in this paper can be interpreted in two distinct ways. First, it can be understood as a realistic model of a real-world coordination setting in which agents have time to prepare and communicate their actions before taking them, but cannot change these preparations instantaneously. Although not always formal, scenarios in which preparation, communication, and incremental commitment go hand-in-hand form an integral part of our social lives. For instance, consider friends deciding whether to attend a dinner party. One might naturally assume that the more guests that show up to the party, the more enjoyable it will be. Often, friends communicate their intentions in the weeks before the party. Various events may cause friends to change their plans, however, with ripple effects on the plans of others. Although no explicit commitment or enforceable contract exists, social norms dictate that going back on one's word is costly; furthermore, the social cost is higher as the date gets closer. Or consider the Republican Senators[2] voting with the Democrats to maintain the Affordable Care Act in the 2017 re-

[2] In the first semester of 2017, five proposals to repeal or drastically change the ACA were defeated in the Senate. While all Senate Democrats voted against all proposals, a group of Republicans was needed to gain a majority and defeat each plan. Of particular notice, the last one, the Health Care Freedom Act known as "skinny repeal", was rejected by the minimum majority. Republican Senators Susan Collins, Lisa Murkowski,

peal effort. They could communicate their intention in the period leading to the vote, and, although they had made no formal commitment, changing their position at the last instant would have been much more dramatic than changing it in advance. The setup in the paper provides a theoretical framework for such scenarios.

Second, the revision mechanism can represent a formal, intentionally designed institution for implementing an efficient outcome. In this sense, the experiment has practical implications for mechanism design in real-world scenarios. Towards this end, it is crucial to understand what part of this complex theoretical mechanism is the force driving the results.

2 Literature Review

A large experimental literature, spurred by Van Huyck et al. (1990), has established that coordination failures—ubiquitous in the real world[3] — are also common in experimental settings. The main contribution of this paper is its examination of how pre-play communication institutions help reduce coordination failures and improve subjects' payoffs. In addition, given the mechanism studied in this paper, our results relate to the literature that focuses on the effects of commitment and real-time interaction on coordination.

In coordination environments, players face a very particular tradeoff, as their preferences are more aligned than in most other strategic situations. The main hurdle for coordination and efficiency is the presence of strategic uncertainty. Some researchers argue that costless pre-play communication could eliminate this hurdle. Blume and Ortmann (2007) and Deck and Nikiforakis (2012) implement a cheap-talk communication phase before the actual play in a minimum-effort game. The pre-play communication in Blume and Ortmann (2007) is done with one round of simultaneous public messages, whereas the protocol in Deck and Nikiforakis (2012) allows for richer interaction, where the subjects have one minute to choose an effort level and can revise the chosen effort at any time. Cheap-talk communication improves coordination and boosts efficiency to 69% and 71%[4] in Blume and Ortmann

John McCain, and every Senate Democrat voted against the bill, giving it a 49-51 defeat (the minimum majority, as the tie-breaking vote, would be cast by Vice-President Mike Pence).

[3] For instance, see Rosenstein-Rodan (1943), Murphy et al. (1989), Li (2012), Matsuyama (1991), and Rodrik (1996).

[4] We use normalized efficiency throughout the paper, as it summarizes the strength of the treatments. Also, normalized efficiency allows us to compare results from frameworks with different payoffs or group sizes. In particular, our paper, Blume and Ortmann (2007), and Deck and Nikiforakis (2012) each use a different payoff specification. Group size in the current paper is the same as in Deck and Nikiforakis (2012) but is different

(2007) and Deck and Nikiforakis (2012), respectively. Despite the ability to update the messages at any second in Deck and Nikiforakis (2012), the efficiency levels in these papers are similar, suggesting that multiple rounds of cheap-talk communication do little to improve efficiency over one round of cheap talk. In this paper, we also find that cheap talk produces efficiency levels around 64%, whether it consists of simultaneous one-shot public messages or multi-round rich communication.

The communication studied in this paper contains no explicit cost of sending messages. However, there is an implicit cost of communication—the inability to revise the intended effort choices instantly. Van Huyck et al. (1993) and Devetag (2005) consider a costly form of pre-play communication (a pre-play auction in each round) and conclude that such an extension enables the players to achieve better coordination on the payoff-dominant profile in coordination games.[5]

To our knowledge, this paper is the first to experimentally study the effects of incremental commitment in coordination games. The impact of incremental commitment on cooperation has been studied in the context of public-goods games. Building on insights by Schelling (1960), Dorsey (1992) was the first to introduce revisions and real-time monitoring in a voluntary contributions mechanism. Looking at those results from a different perspective, Duffy et al. (2007) test theoretical predictions about the dynamic voluntary-contribution game in Marx and Matthews (2000) and show that, whereas a dynamic setting increases the rate of contributions compared to the static setting, the results do not seem to be driven by the theoretically identified forces. Fundamental differences exist between the forces that impede coordination on the Pareto-efficient equilibrium in coordination games and the forces that drive the lack of cooperation in the public-goods provision and social dilemmas. In the latter, the tradeoff is between efficiency and individual rationality. In contrast, in coordination games, the miscoordination is a result of the multiplicity of equilibria along with a lack of selection criteria, leading to strategic uncertainty. Contrasting our results with Duffy et al.'s (2007) highlights how different the two settings are. In this paper, we show not only that pre-play revisions significantly improve efficiency in coordination games, but also that the efficiency gains are driven by theoretical arguments on which the results are based.

Roy (2017) experimentally studies the market competitiveness in a Cournot duopoly

than in Blume and Ortmann (2007). We provide more details of the measure in the results section.

[5] Crawford and Broseta (1998) provide theoretical foundations for such experimental results.

in which firms can simultaneously revise their targeted quantities before the final production. Building on the revision-games theoretical results in Kamada and Kandori (2017), Roy (2017) tests the prediction that a synchronous revision Cournot duopoly may result in higher collusion than in the case without stochastic interaction. Although there is some overlap in the theories that predict more collusion in Roy (2017) and higher coordination in our paper, the forces behind them are fundamentally different. First, when a revision phase is introduced to a Cournot duopoly, the set of possible equilibrium outcomes increases, and collusion becomes theoretically sustainable. By contrast, the introduction of a revision phase to coordination games shrinks the set of equilibrium-supported outcomes to the unique Pareto-efficient profile. In addition, the revision phase studied theoretically in Kamada and Kandori (2017) and experimentally in Roy (2017) has synchronous revision opportunities. In contrast, the theory developed in Calcagno et al. (2014) highlights that, in coordination games, asynchronicity is key to mitigating strategic uncertainty. Inefficiencies in coordination settings and the Cournot duopoly are the result of fundamentally different forces, calling for different mitigation mechanisms. In coordination settings, we show that introducing incremental commitment leads to credible communication that will effectively help agents coordinate on Pareto-dominant outcome.

3 General Framework

3.1 Component Game

Consider a general normal-form game $(I, (E)_{i\in I}, (\pi_i)_{i\in I}))$, where I is a finite set of players $I = \{1, 2, ..., n\}$; E is a finite set of effort levels available to each player i; and $\pi_i(\mathbf{e})$ is the payoff for player i given the strategy profile $\mathbf{e} \in \mathbf{E}$, where $\mathbf{e} = (e_i)_{i\in I}$ and $\mathbf{E} = \prod_{i\in I} E$. Throughout the paper, we focus on a particular payoff structure, the minimum-effort game, with

$$\pi_i(\mathbf{e}) = \gamma + \alpha \cdot \min_{j\in I} e_j - \beta \cdot e_i \tag{1}$$

and $\alpha > \beta > 0$. A player's payoff decreases with her choice of effort and increases with the minimum effort among all the players. This is a game of common interest,[6] as the strategy profile $\bar{\mathbf{e}}$ strictly Pareto dominates any other profile. Let $\underline{\pi_i(e)}$ be the worst possible payoff

[6] A game is a common-interest game if it has a strictly Pareto-dominant action profile.

for player i, reached when i chooses $\bar{e}$ and at least one player in her group plays $\underline{e}$.

Equilibrium Analysis: The normal-form game described above has multiple pure strategy Pareto-ranked Nash equilibria. The profile in which all players choose the same pure strategy is a strict Nash equilibrium. These equilibria can be Pareto-ranked by the effort choice: the higher the effort, the more efficient the equilibrium. In particular, let $\bar{e}$ be the highest element of E and let $\underline{e}$ be the lowest; then, $\pi_i(\bar{\mathbf{e}})$ is the highest equilibrium payoff for player i, whereas $\pi_i(\underline{\mathbf{e}})$ is the lowest possible equilibrium payoff, in which $\bar{\mathbf{e}}$ ($\underline{\mathbf{e}}$) denotes the profile where all players choose $\bar{e}$ ($\underline{e}$).

3.2 Pre-play Communication

Theoretical work regarding cheap-talk pre-play communication in coordination games has focused on evaluating the credibility of a message profile. The idea is that pre-play communication will promote Pareto-efficient Nash equilibrium play if, when players communicate their intentions to take a certain action, their messages are credible. The literature has proposed several requirements for a message to be considered credible.

The early literature looks at one-way communication and analyzes the credibility of a message in isolation. For instance, Farrell (1988) postulates that a message is credible if it is self-committing: if the message is to be believed, a sender's best response is to follow the intention stated in the message. If we consider the minimum-effort game with one player sending a public message to all other players, then sending an efficient-effort message is self-committing. If all receivers believe the message and choose the efficient effort, the sender's optimal choice is to follow the message and choose the efficient effort as well. Aumann (1990) challenges the above reasoning, focusing on whether the sender has a strict preference over the other players' strategy choices. The author argues that, when the sender wants the receiver to believe the message, whether or not she intends to act in accordance with it, the message has no credibility. For Aumann (1990), a message will induce effective communication only if it is self-signaling: the sender wants her message to be believed if, and only if, she plans to follow the intention in the message. Note that, in the minimum-effort game, a player weakly prefers that other players choose the efficient effort level, independent of her choice; hence, messages signaling the intent to choose efficient effort are not self-signaling.

Self-committing and self-signaling are both concepts that relate to individual messages.

Although the definitions could be intuitively generalized to the case of multilateral communication, message credibility needs to be defined for profiles of messages, not for individual messages. A player can simultaneously be a sender and a receiver of a message, and a player might send a message linked to one equilibrium and receive a message linked to another equilibrium. In particular, Blume (1998) argues that communication makes an equilibrium profile more attractive for a player only if all players communicate homogeneously, agreeing on the equilibrium in question.[7] In a minimum-effort game with one-shot multilateral communication, if the chosen message profile is homogeneous, then the associated equilibrium profile could be considered more salient. However, no consensus exists on how to interpret heterogeneous message profiles, and the standard prediction is that communication will be ignored.

3.3 Asynchronous Revision Game

Consider an environment in which players need to prepare their actions before they execute them. We model this situation following Calcagno et al. (2014): time is continuous, $t \in [-T, 0]$, and the component game is played once and for all at the end of the pre-play phase, at time 0. The revision game proceeds as follows: (i) At time $-T$, an initial effort profile is in place. It can be exogenously given to the players, or each player can simultaneously and independently choose an effort level before the pre-play starts; (ii) in the time interval $(-T, 0]$, each player independently obtains revision opportunities according to a random Poisson process with symmetric arrival rate $\lambda > 0$, at which point they can change their current effort level. Note that, because the Poisson processes are independent, the revision opportunities are awarded asynchronously with probability 1; and (iii) at the end of the countdown, $t = 0$, the posted effort profile is implemented, and each player receives the payoff according to the payoff specification of the component game.

A public history is a sequence of posted efforts and the history of revision opportunities for each group member, $\mathcal{H}_t = \big\{\{\mathbf{e}(\tau)\}_{\tau\in[-T,t)}, \{o(\tau)\}_{\tau\in[-T,t)}\big\}$, where $\mathbf{e}(\tau) = (e_1(\tau), ...,$

[7] The results in Blume (1998) are achieved with costless messages and the additional assumption of messages having some a priori informational content. Hurkens (1996) first obtained similar results with costly messages and no additional assumptions on messages. Moreover, the result extends to two-sided communication if there are only two players, and the underlying game is common interest (see, also, Sobel (2017), where iterated weak dominance can select the Pareto-efficient outcome with one-sided pre-play communication in two-player games). However, the results fail even with common interest coordination games when there are three or more players.

$e_n(\tau))$ is a profile of efforts chosen at instant τ, $e_i(\tau) \in \mathbf{E}$, and $\mathbf{o}(\tau) = (o_1(\tau), ..., o_n(\tau))$ indicates who (if anyone) had a revision opportunity at instant τ, $o_i(\tau) \in \{0, 1\}$. Let $\mathcal{H} := \cup_{t \in [-T,0]} \mathcal{H}_t$ be the set of all possible public histories. A strategy for player i is, at each instant, a mapping from all possible histories to an effort level: $\sigma_i : \mathcal{H} \to \Delta(E)$.

The game described above is a sequential game with multiple rounds of asynchronous play. As players observe all the past events in the revision game, the natural solution concept is a subgame perfect equilibrium. We refer to the subgame perfect equilibrium of the revision game as *revision equilibrium*. Before we proceed to the main result, we first introduce a definition from Calcagno et al. (2014) [8] that we apply to the minimum-effort game.

Definition 1 *Calcagno et al. (2014)*
A component game with common interest is said to be a K-coordination game if, for any pair of players $i, j \in I$ and strategy profile $\mathbf{e} \in \mathbf{E}$,

$$\frac{\pi_i(\bar{\mathbf{e}}) - \pi_i(\mathbf{e})}{\pi_i(\bar{\mathbf{e}}) - \pi_i(\underline{\mathbf{e}})} \leq K \frac{\pi_j(\bar{\mathbf{e}}) - \pi_j(\mathbf{e})}{\pi_j(\bar{\mathbf{e}}) - \pi_j(\underline{\mathbf{e}})}. \tag{2}$$

A game is a K-coordination game if each player can decrease other players' payoffs by, at most, K times her own cost of punishment. The constant K captures how similar the players' preferences are. The smaller K is, the more similar are players' preferences. In particular, if $K = 1$, the game is a pure coordination game, and players have identical payoffs at any outcome. Any finite game with common interest is a K-coordination game for some finite constant $K \geq 1$.

The minimum-effort game is a K-coordination game if $\frac{\alpha}{\alpha - \beta} \leq K$. We now apply Theorem 2 from Calcagno et al. (2014) to the symmetric minimum-effort revision game defined in Section 3.1.

Proposition 1 *Calcagno et al. (2014)*
In an asynchronous revision game with symmetric arrival rate of revision opportunities, if the component game is a K-coordination game with the strict Pareto-dominant action profile, $\bar{\mathbf{e}}$, and the game satisfies $(n-2)K < (n-1)$, then for any $\varepsilon > 0$, there exists $T' > 0$ such that for all $T > T'$, all revision equilibria have $\mathbf{e}(\mathbf{0}) = \bar{\mathbf{e}}$ with probability higher than $1 - \varepsilon$.

[8] See Takahashi (2005) for the definition and discussion of the concept.

According to Proposition 1, in a revision equilibrium of a long enough revision game, all the players choose the efficient effort profile in the payoff-relevant moment with probability close to one. Interestingly, this result holds independent of the effort configuration at the beginning of the revision phase. If the time horizon is long enough, then at $t = 0$, all players will be choosing the efficient-effort profile (with probability $1 - \varepsilon$) independent of the effort profile at $-T$, even if all players start with the minimum effort, if it is randomly determined, or if players choose simultaneously at $-T$. The proof of Proposition 1 is an application of Theorem 2 from Calcagno et al. (2014) to the case of symmetric revision processes considered in this paper (further details are in Appendix A).

Next, we discuss the argument of the proof. The proof begins by constructing a lower bound for the payoff of a player who chooses the highest effort well before the deadline. This bound naturally depends on other players' choices; in particular, it is a function of how many other players are choosing the efficient effort. The main step of the proof is to show that, in any subgame perfect equilibrium, independently of how many players were choosing the efficient effort at that time, the lower bound converges to the efficient payoff if there is enough time before the deadline. This is done by induction on the number of players choosing the highest effort, $\bar{e}$, at a time t far enough from the deadline.

Formally, the proof can be divided into two parts. The first part shows that if all players are choosing the highest effort at a time t, then there is a unique subgame equilibrium payoff, $\pi(\bar{e})$. That is, the Pareto-dominant equilibrium profile, $\bar{\mathbf{e}}$, is absorbing: if a subgame starts with the effort profile $\bar{\mathbf{e}}$, then the unique subgame perfect equilibrium in that subgame has all players preparing the maximum effort along the equilibrium path. The second part of the proof, the inductive argument, shows that if the lower bound on a player's payoff converges to $\pi(\bar{e})$ when $k + 1$ players are choosing $\bar{e}$ at time t, then it also converges when only k players are choosing $\bar{e}$ if the deadline is distant enough. Thus, when far from the deadline, independent of the current effort choices, by selecting the highest effort, a player guarantees herself a payoff close to the efficient payoff with probability close to one.

A key argument behind the result is the player's ability to influence other players' subsequent choices, which relies on the existence of proper subgames in the revision game. If a player cannot observe the effort choices of other players or how others are responding, then the revision phase has no proper subgame, and the repetition of a static Nash equilibrium is a revision equilibrium of the extended game. Unlike the key forces highlighted above that are crucial for the results to hold, the model relies on institutional details and assumptions that are not essential. For instance, for the minimum-effort game, the condition stated in the Proposition 1 is sufficient, but not necessary.[9] Furthermore, neither the continuous time nor independent Poisson distribution of revision opportunities is crucial for the results. In Appendix B, we consider a discrete-time pre-play phase with a non-independent Bernoulli process for the revision opportunities, and we show that the theoretical results remain unaltered.

Proposition 1 highlights that a player's best response must depend on the time left before the deadline. For instance, consider that, at a time $-t$, all players are choosing the minimum effort, and player i has a revision opportunity. If t is small, it is clear that it is optimal for player i to revise her effort choice to her myopic best response—the minimum effort. Any other choice of effort would give her higher payoffs only if all other players revised their choices. With t small enough, the probability of no revisions being awarded converges to one. However, if t is large enough, the proposition dictates that it is optimal for player i to choose in a forward-thinking way, to revise her effort up, and to initiate a chain reaction that will end with all players choosing the highest effort. In Appendix C, we provide more details on how the best response is affected by the amount of time remaining before the deadline, given our payoff parameters in the experiment (in Section 5.4 we examine subjects' revisions as the deadline approaches).

We proceed by describing how we design an experiment that closely replicates the conditions of our setup to test the power of the pre-play revision mechanism in aiding coordination. Implementing this institution in the lab presents several challenges. One challenge is that the theoretical framework used in Calcagno et al. (2014) relies on continuous time with revision opportunities arriving with the Poisson distribution. There is no continuous time implementation in the lab.[10] To that end, we extend the theoretical results in Proposition 1 to a framework in which time is discrete, and, at each instant, a revision opportunity is awarded to the group with probability p. If awarded, the opportunity is randomly distributed

[9] In Calcagno et al. (2014), the authors show that the condition is tight for the general case. That is, for any $K > 1$, it is possible to find a K-coordination game such that the condition is necessary and sufficient for the proposition. In this paper, we focus on a particular game: the minimum-effort game.

[10] See Friedman and Oprea (2012) and Bigoni et al. (2015) for recent studies implementing (quasi-)continuous time in the lab. We would like to thank Bigoni et al. (2015) and Friedman and Oprea (2012) for sharing their code with us.

to a player, with equal probability to all players.[11] Even then, the game involves frequent interaction among players, and they need to have complete information at every period. Thus, a second challenge is that each player's revision opportunity and posted effort, as well as the history of posted efforts and revisions, should be available to all players at all times. To compile all of this information and make it easily understandable to our subjects, we create a graph that summarizes all the key points and represents the players' efforts in different colors. Every time a player receives a revision opportunity, a dot shows up on that player's action line. This graph summarizes all of the key information and makes it easily accessible to the subjects. The next section presents a more detailed explanation of our graph and the entire experiment.

4 Experimental Design

All of the experimental sessions were conducted at the Center for Experimental Social Science (CESS) laboratory at New York University (NYU), using the software z-Tree (Fischbacher (2007)). All participants were NYU students. The experiment lasted about 45 minutes, and subjects earned, on average, \$17, which included the $\$8$ show-up fee. The experiment consisted of six different treatments, and each subject participated in only one. In each session, written instructions were distributed to the subjects and also read aloud.[12]

In all treatments, participants were randomly divided in *groups of six*, and they participated in a sequence of *10 rounds* as a part of that group. In each round, the group played the minimum-effort game with effort choices from 1 to 7 ($E = \{1, 2, 3, 4, 5, 6, 7\}$), and the same payoff function: $\pi_i(e) = .18 - .04 \cdot e_i + .2 \times \min_{j \in I} e_j$. The payoffs were described to subjects in matrix form, and the subjects then took a comprehension test to ensure that they understood the payoff structure. After ten rounds, subjects took a short survey and were paid their final payoff, which was the sum of the payoffs from all ten rounds, and the show-up fee (survey results are summarized in Appendix G).

4.1 Treatment 1: Baseline

The baseline treatment replicated the standard control treatment in the literature. Subjects played the normal-form one-shot game described above. After each round of playing a stan-

[11] See the formalization in Appendix B, and the result in Proposition 2.
[12] Instructions used in our experiment can be found in Appendices J, K, L, M, N, and O.

dard simultaneous minimum-effort game, participants received feedback on the minimum number chosen in their group in that round. This information was the only history available to the subjects in the baseline treatment (as in Van Huyck et al. (1990)).

4.2 Treatment 2: Revision Mechanism (RM)

The primary treatment in the paper is the revision mechanism, which replicates the theoretical setting described in Section 3.3. In this treatment, each round began with all members of the group simultaneously choosing a number from 1 to 7. Once all group members made their choices, a graph[13] appeared, and a one-minute countdown began. In Figure 1, we present an example of the graph after 30 seconds of the countdown. The time in seconds is on the horizontal axis, and the number chosen by each of the group members is on the vertical axis. The initially chosen numbers are along the vertical line above the zero-second mark. Each player is represented on the graph by a different color. As the countdown progressed, at any time, any member of the group could change her chosen number by placing the cursor on the desired number on the left side of the screen. When a subject selected a number, the respective button turned green (see the number 4 in Figure 1). The number posted on the graph only gets updated when the player received a revision opportunity.

On average, a subject received eight revision opportunities in one round. Formally, at every second, the group had an 80% chance of receiving a revision opportunity; if that occurred, then the six group members had an equal probability of $1/6$ of receiving the revision opportunity.[14] Only the numbers posted at the end of the countdown mattered for the payoff. The initially chosen efforts and all the revision effort choices were payoff-irrelevant.

Consider the actions of player Green (thicker line on the graph), whose screen is in Figure 1. Along the vertical line above the zero-second mark, we see a green dot in interval 2, which means that Green's initial choice was 2. A dot on the green line (thicker line) at the five-second mark indicates that Green received a revision opportunity; however, because the

[13] We explained the graph in great detail in the instructions, and all subjects took a comprehension test regarding the graph and payoff table.

[14] The theoretical result in Proposition 1 requires the revision opportunities to be frequent enough or the length of a round to be long enough (these two parameters are interchangeable). In Appendix C, we numerically compute the time horizon needed for our results to hold, given .8 probability of revision frequency used in RM treatment the horizon is calculated to be about 12 seconds. Furthermore, in Appendix E, we use the data to test whether the parameters T and λ in the RM treatment bind players' choices, and we conclude the specifications were not binding.

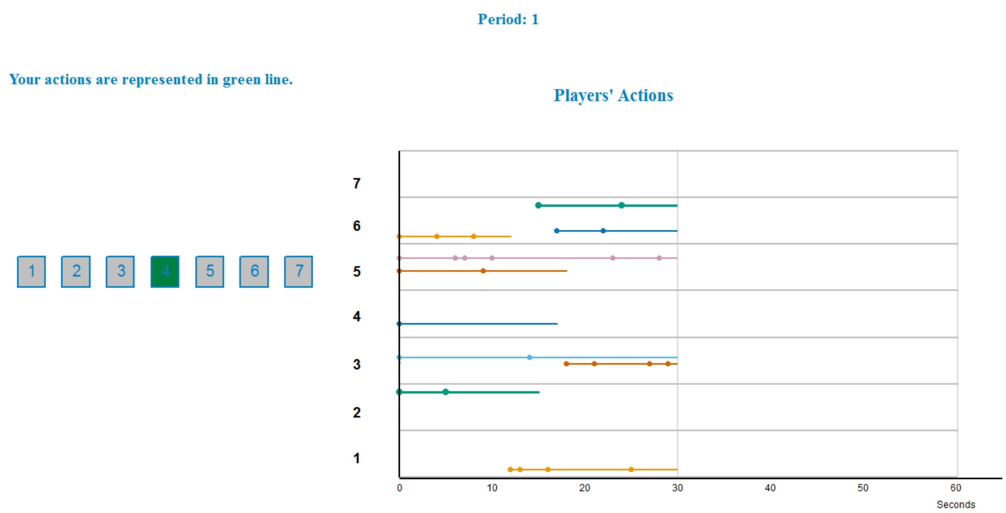

Figure 1: Sample Screen after 30 Seconds

effort after that was not updated, Green had not changed the intended effort, still choosing 2. At the 15-second mark, we see a shift of the green line from the effort-2 interval to the effort-6 interval. This shift implies that in the 15th second, Green received the revision opportunity, before which she switched her effort from 2 to 6. At about the 25-second mark, the green dot on the line reveals an unused revision opportunity, as the green line is still in interval 6. On the left side of the graph in Figure 1, the number 4 is highlighted, which implies that the player whose screen we are observing switched her intended effort from 6 to 4. However, a revision opportunity had not yet occurred; thus, the posted effort on the graph is still 6.

We collected data on each player's intended effort and posted effort at every second. Having two streams of data—what subjects want to post and what is actually on the graph—allows us to look into best responses; these two types of information become even more important when we vary the rate of revision opportunities and make revisions less frequent; see Section 4.4.

4.3 Cheap-Talk Treatments (S-CT and R-CT)

Standard Cheap Talk: The standard cheap-talk (S-CT) treatment offered subjects multilateral one-shot communication, similar to the main communication treatment in Blume and Ortmann (2007). In this treatment, before subjects made their payoff-relevant effort choices, they simultaneously sent a public message (a number from 1 to 7). This was followed by 60 seconds during which subjects saw all the messages sent by their group members (including own message).[15] After the subjects saw the messages, buttons appeared, and they made their payoff-relevant effort choices (all the group messages were visible on the screen when subjects were making their payoff-relevant decisions). At the end of the round, the subjects saw a feedback page with their choice and the minimum number chosen by the group.

Revision Cheap Talk: The communication part of the revision mechanism involves multiple rounds of messages. To ensure that we separate the effect of commitment from the implementation of communication, we added a communication treatment, implementing revision-mechanism communication without the commitment component. The revision cheap-talk (R-CT) treatment followed the RM pre-play phase protocol. First, all members of the group simultaneously chose an integer from 1 to 7; then, once everyone made a choice, the one-minute countdown began. As in the revision mechanism, all members of the group saw the same real-time graph, and the effort chosen was updated only when a revision opportunity was awarded.[16] In contrast to RM, the choice at the end of the countdown was not payoff-relevant in R-CT. Once the 60-second countdown was over, a new screen appeared, and subjects chose an integer from 1 to 7 that would determine their payoffs. These final choices were the only payoff-relevant decisions in the round. Any choices or revisions made during the 60-second pre-play were not payoff-relevant.

4.4 Infrequent-Revision Mechanism (I-RM)

In the revision mechanism, players commit to their chosen efforts gradually. As time passes, the likelihood of not having a revision opportunity before the deadline increases; thus, a subject is more likely to get stuck with the current effort choice as her final payoff-relevant effort. In RM, a group received a revision with a probability of $.8$, which, on average, provided each subject with eight revisions per round. To study the importance of this gradual commitment, we increased the level of commitment by drastically reducing a group's probability of having a revision opportunity from .8 to .1. In the revision mechanism, the chance of having no more revisions 60 seconds before the deadline was approximately 0.01%, while

[15] To ensure that subjects spent the same amount of time in the lab and had an experience similar to that of the RM treatment, we displayed the messages sent by subjects on a graph and gave the subjects 60 seconds to make payoff-relevant effort choice.

[16] The distribution of revisions was the same as in RM.

in I-RM, it was 36%.

Note that, given the fixed time interval of 60 seconds, no theoretical argument exists for I-RM to increase coordination on the efficient equilibrium. In Appendix C, we numerically solve the game with 0.1 as the probability of a revision opportunity, and we find that at least 164 seconds per round would be needed for the theoretical results to hold. However, the treatment still allowed subjects to attempt to communicate; moreover, in contrast to the baseline, because of the graph subjects got to see the effort choices of all the group members, not just the minimum effort of the group.

4.5 Random-Initial-Choice-Revision Mechanism (R-RM)

To test the forces in place for the main theorem and to ensure we observe the effect of revision pre-play for the reasons provided by the theory, we need to understand players' dynamic behavior, which requires heterogeneity in initial choices. Interestingly, the theory can be extended to the case of random initial choices. If the initial choices are randomly picked for the players, then, with a long enough pre-play phase, we should observe the efficient outcome with probability close to 1.

We introduced a treatment called the random-initial-choice-revision mechanism (R-RM), in which the initial choices were randomly[17] chosen for the subjects, but the rest of the round was executed identically to the RM protocol. We know, theoretically, that the outcomes of this treatment should be similar to those of RM; however, we got a much richer best-response behavior due to the initial heterogeneity of effort choices.

Table 1 summarizes our experimental design and highlights the differences in our six treatments between the two main dimensions: communication and commitment.

5 Results

In this section, we present our experimental results and shed light on how the asynchronous revision pre-play phase improves coordination on the more efficient equilibrium. We first establish the overall payoff gains of the revision mechanism over the baseline and the standard cheap talk treatments. In addition to demonstrating a payoff gain, we show that in

[17] The random process for the initial-choice assignment is uniform over all possible efforts, and all groups face the same initial effort distribution.

[18] One session of the baseline treatment was voided because one of the subjects publicly announced his intended action, and asked others to play the same. We ran an extra session to replace the voided session.

Table 1: Experimental Design

Treatment	Communication	Commitment	No. of Subjects
Baseline[18]	None	NA	48
Revision Mechanism (RM)	Pre-play revision	Gradual	48
Standard Cheap-Talk (S-CT)	One-shot	None	48
Revision Cheap-Talk (R-CT)	Pre-play revision	None	48
Infrequent RM (I-RM)	Pre-play revision	Abrupt	48
Random RM (R-RM)	Pre-play revision	Gradual	48

RM, at the payoff-relevant instant, players choose a higher minimum effort (closer to the efficient choice) and coordinate more often. The rest of this section is devoted to further understanding the forces behind these efficiency gains.

The introduction of the pre-play revision mechanism over the one-shot game in the baseline allows players to coordinate more often and on the Pareto-efficient equilibrium. This improvement is reflected in many of the variables presented in Figures 2 and 3. For instance, players' payoffs are substantially higher; groups coordinate significantly more often, and subjects choose the Pareto-efficient action significantly more frequently. However, observing such a stark difference between the baseline and the RM is not very informative since the baseline treatment does not allow any communication among subjects. We know from the literature[19] that one round of public multilateral cheap-talk communication provides higher levels of coordination on the Pareto-efficient equilibrium and better payoffs overall than baseline treatment does. Therefore, we compare the revision mechanism not only to the baseline treatment but also to the standard in the literature: one round of public multilateral cheap-talk communication.

The revision mechanism differs from S-CT in two critical ways: (i) it offers a richer communication protocol involving multiple rounds of public communication; and (ii) the communication is not cheap talk. We analyze the relative importance of each of the two factors for the efficiency gain and its effects on communication among subjects. In addition, we analyze two more treatments to test the robustness of the theory behind our primary treatment. We focus on the frequency of revision opportunities and on the dynamic behavior during the pre-play phase to establish that the theoretically identified forces do, indeed, drive

[19] In particular, see Blume and Ortmann (2007).

the observed efficiency boost.

(a) Efficiency (b) Average Payoff

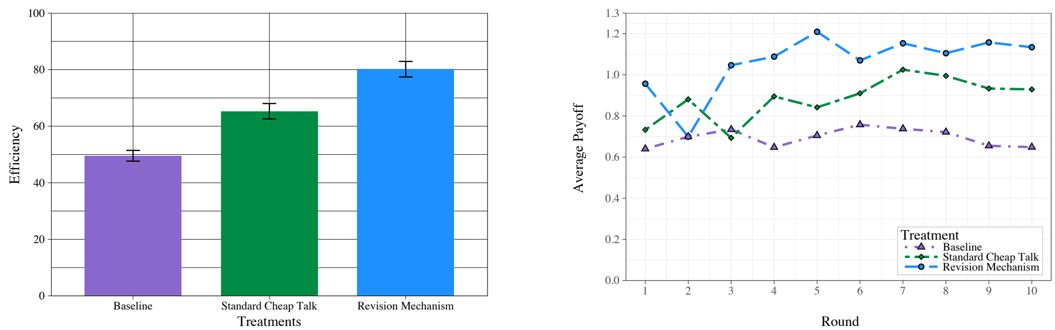

Figure 2: Baseline vs. Standard-Cheap Talk vs. Revision-Mechanism Treatment

We first focus on average efficiency and average payoffs (see Figure 2). Following the literature, we calculate normalized efficiency as

$$\textit{Efficiency} = \frac{Actual - Min}{Max - Min}, \tag{3}$$

where $Actual$ is the average amount earned in a treatment, and Min (Max) is the average minimum (maximum) possible amount that a subject can earn.[20] Results are displayed in Figure 2a. The RM efficiency measure is 80%, whereas, in the S-CT treatment, the efficiency is 64%. The introduction of the revision mechanism restores more than half (61%) of the efficiency loss in the baseline treatment. Our standard cheap talk treatment result is consistent with the results in Blume and Ortmann (2007) and Deck and Nikiforakis (2012), where one-shot and multi-round cheap-talk communication result in normalized efficiency measures of 69% and 71%, respectively.[21]

[20] The average minimum payoff a group can earn occurs when one player chooses the minimum effort, and all others choose the maximum effort. The average maximum is reached when all players choose the efficient profile.

[21] Although Blume and Ortmann (2007) do not calculate the normalized efficiency; we calculated it using the data provided by the authors. Actual Average Payoff is .95, Average Minimum Payoff is $.1(6)$; Maximum Payoff is 1.3; thus, $\textit{Efficiency} = \frac{Actual - Min}{Max - Min} = .691$. Normalized efficiency is a useful measure that allows us to compare the results in our paper to those in the literature. Payoffs in Blume and Ortmann (2007), Deck and Nikiforakis (2012), and our paper are different, but normalized efficiency captures the strength of the treatments.

In Figure 2b, we compare the efficiency of each treatment by analyzing the average payoff in each round separately. Subjects earn substantially more in the revision mechanism than in the cheap-talk treatment from the third round onwards. Figure 2b shows a divergence in average payoffs, but the difference between subjects' total earnings in these two treatments is even stronger—the payoff distribution in the RM first-order stochastically dominates the distribution in the S-CT treatment, and a Mann-Whitney U (MWU) test of equal distributions is rejected at $p < 0.01$.

Figure 2 establishes that payoffs are higher in the RM treatment than in the baseline and the S-CT treatments. Based on the payoff function for the minimum-effort game (see equation 1), deviations from the efficient equilibrium reduce payoffs in two distinct ways. First, through the inefficient minimum effort chosen, which affects all players' payoffs, and second, through miscoordination from the minimum effort, as players select different efforts. Which of these forces drives the higher payoffs in the RM compared to other treatments? Figure 3 documents that improvements in both directions drive the observed increase in payoffs. In RM we observe (i) more frequent selection of the efficient effort; and (ii) more coordination on any particular equilibrium.

We begin by showing that the RM treatment fosters a more frequent choice of the efficient effort level. First, consider the average minimum effort, shown in Figure 3a.[22] The average minimum effort chosen in the RM is significantly higher than in the S-CT treatment (the hypothesis of equal minimum effort distributions is rejected using a MWU test, $p < 0.01$).[23] Second, we examine the frequency of efficient effort, shown in Figure 3b. The frequency with which the highest effort appears in the S-CT treatment is always lower than in RM. Subjects choose the efficient effort, on average, 50% more often in the RM, and the difference stays roughly stable as rounds progress. We also test the null hypothesis of equal distributions of effort choices in both treatments in all rounds combined. An MWU test rejects the hypothesis with $p < 0.01$. These results establish that RM performs better than the S-CT for coordinating on the Pareto-efficient equilibrium.

We now focus on whether RM provides more coordination on any particular equilibrium. To examine this statement, we use two measures. First, we consider the number of groups that perfectly coordinate on any equilibrium profile (not necessarily the efficient one). The

[22] Group-level data for each treatment can be found in Appendix F.
[23] See Table 5 in appendix H for details on all hypotheses tests in the paper.

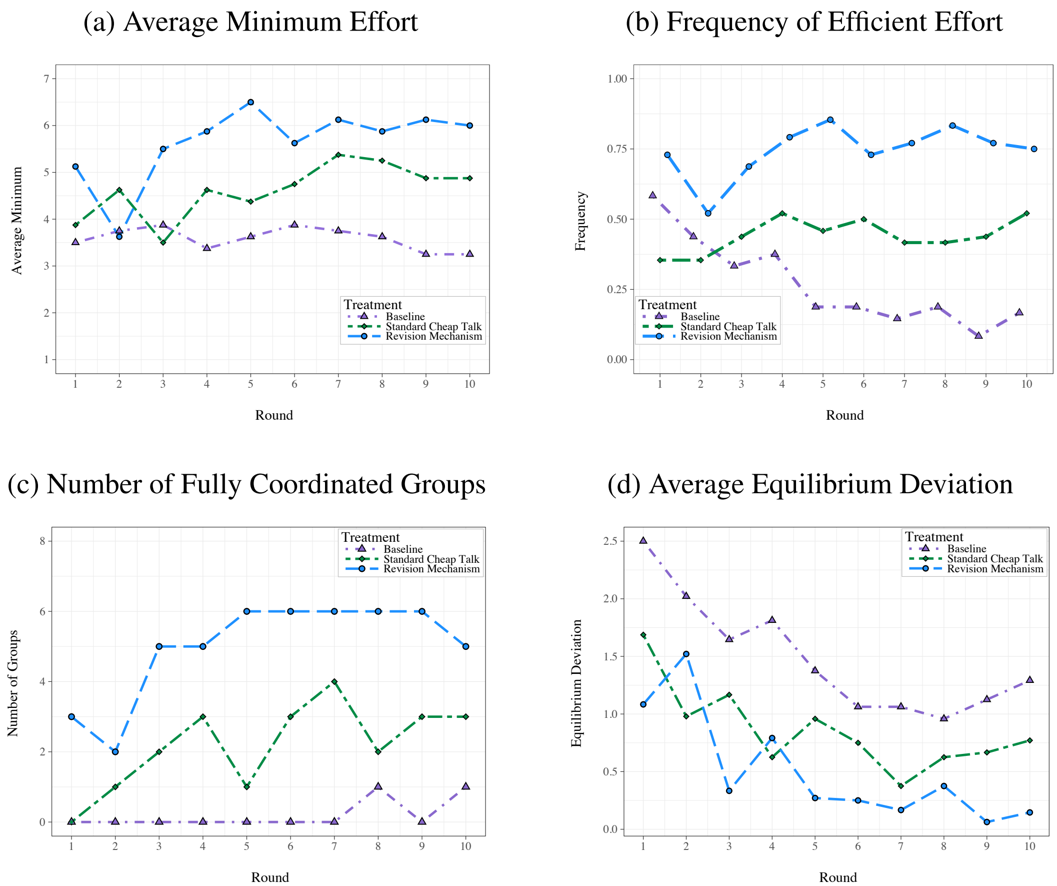

Figure 3: Baseline vs Standard Cheap Talk vs Revision Mechanism

results displayed in Figure 3c highlight that in every round, more groups coordinate in RM than in the S-CT treatment. Second, to analyze how far the groups are from full coordination, we introduce a new measure that we call *equilibrium deviation*. For each group, J, we calculate the minimum effort chosen in that group, $\min_{j \in J} e_j$. We then average the distance of each player from this myopic best response, $EqDev_J = \frac{1}{6} \sum_{i \in \{1,\ldots,6\}} (e_i - \min_{j \in J} e_j)$. Finally, we average the equilibrium deviation for all groups to obtain $EqDev$.[24] The results are displayed in Figure 3d. As we see in Figure 3d, the average equilibrium deviation in the first few rounds of RM and S-CT is similar, and as rounds progress, both deviations decline. However, the equilibrium deviation in RM is, in most of the later rounds, very close to zero,

[24] The efforts are discrete and bounded, and the equilibrium-deviation measure captures the deviations from equilibrium without suffering from bound asymmetry issues that standard deviation does.

as six out of eight groups' equilibrium deviation is 0—all the players in those six groups choose the same effort level. Given the results displayed in Figures 3c and 3d, we conclude that RM provides more coordination on any equilibrium.[25]

The standard theoretical prediction for baseline treatment is that players would choose some Nash equilibrium profile. The fact that groups are unable to coordinate on any equilibrium profile in the baseline—at most, one group out of eight fully coordinates on a profile in any of the ten rounds—highlights the importance of communication for groups to achieve coordination. Communication alters the game in two subtle ways: (i) it allows players to "listen" to others and change their actions based on what others have shared about their intentions; and (ii) it enables players to communicate to influence other players. Along those lines, we can look at the initial choice for RM. As we verify in Appendix C, given our parameters, all players should initially choose effort 7, and all groups should, thus, immediately coordinate on it. Not all subjects choose seven initially, on average, 86% of them do.[26] However, in RM, even if players miscoordinate in the initial instant, the pre-play phase allows them to communicate and revise their efforts to coordinate. In the next subsection, we further analyze the importance of communication for the efficiency gains documented above.

5.1 Communication and Commitment

To understand why the revision mechanism improves both individuals' ability to coordinate and the actual strategy profile on which players coordinate, we study the forces behind our central treatment. RM departs from the S-CT in two important ways: first, it improves players' capacity to communicate by offering a rich multi-round communication protocol; and second, it makes players commit incrementally to their words as the deadline approaches.

To separate the contribution of each of these distinct forces, we endow the players with a richer cheap-talk communication protocol—the revision cheap talk (R-CT). In this treatment, players have the same multi-round asynchronous public message communication protocol as in the revision mechanism; however, the effort chosen in the last instant is not binding. The

[25] We provide regression analysis for the four variables analyzed above to check the robustness of the results presented in Figure 3 (see Appendix H, Table 3). In the regression analysis, we can control for subject-specific information, and we cluster the standard errors at the group level. The results further highlight the benefits and the robustness of RM.

[26] The fraction of subjects initially choosing 7 in the first round is about 75% and grows in the next two rounds and stabilizes between 85% and 90%.

fact that RM and R-CT provide subjects with the same communication (but distinct levels of commitment) allows us to examine the following two questions: (i) how much gain is due to the rich communication protocol embedded in the revision mechanism? And (ii) how much does the addition of commitment add. Compared to the baseline treatment, RM restores 61% of the efficiency loss. Using the R-CT treatment, we find that approximately half of the efficiency gain is due to the communication protocol. The addition of commitment is responsible for the other half (52% of the efficiency gain is due to communication, while the addition of gradual commitment is responsible for the remaining 48%).

(a) Frequency of Highest Effort (b) Number of Fully Coordinated Groups

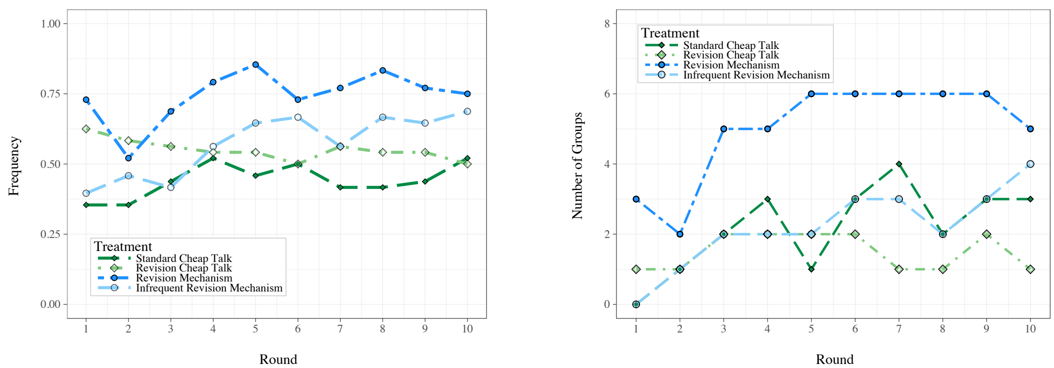

Figure 4: Communication and Commitment

We now turn our attention to understanding how much the richer communication protocol can help subjects coordinate. First, note that the richer communication protocol in R-CT does not improve efficiency or provide subjects with higher payoffs when compared to S-CT. The average efficiency in S-CT and R-CT are, respectively, 64.1% and 64.4%. A test of the null hypothesis that the distributions of subjects' payoffs in S-CT and R-CT are identical cannot be rejected (MWU, $p = 0.523$).

We can further understand how similar the subjects' behavior is under the two treatments by looking separately at (i) how frequently the subjects select the highest effort and (ii) whether they fully coordinate. Figure 4a shows that subjects choose the efficient effort significantly more often in RM than in either of the cheap-talk treatments.[27] Also, we see that from the fourth round onwards, the frequency of highest effort is very similar for both

[27] We test the null hypothesis of equal distributions of effort choices in RM and R-CT treatments in all rounds combined (MWU, $p < 0.01$).

cheap-talk treatments, around 50%. Second, we focus on coordination on any particular equilibrium profile, and in Figure 4b, we see the number of fully coordinated groups. While in RM, a considerable fraction of the groups fully coordinate, in S-CT and R-CT, the fraction is significantly smaller.

The above results highlight the importance of commitment to reach the effects discussed in the previous subsection. The efficiency gains provided by RM, when compared to those of S-CT, seem to originate from the fact that RM forces subjects to incrementally commit to their words. In the next section, we examine how subjects commit in the revision mechanism, focusing on the importance of the frequency of revision opportunities.

5.2 Gradual commitment

In RM, players commit to their chosen actions in an incremental way. As time passes, the likelihood of having no remaining revision opportunities before the deadline—thus the commitment—increases gradually. To understand whether this gradual commitment allows players to use the early moments of the pre-play phase to communicate their intentions and, thus, to coordinate on more efficient outcomes, we now compare the revision mechanism with distinct revision probabilities. Whereas in RM, in each round, a revision was awarded to the group with probability $p = 0.8$, in the infrequent revision mechanism (I-RM), that probability was $p = 0.1$. The number of expected revision opportunities per subject drops from eight to one per round. This change in revision frequency also impacted the probability of committing. In RM (I-RM), the chance of having no more revisions is approximately 0.01% (36%) when 60 seconds remain before the deadline; 1% (60%) when 30 seconds remain; 10% (80%) when 15 seconds remain; and 50% (90%) when five seconds remain.

Given the fixed time interval of 60 seconds and the low probability of revision opportunities, I-RM does not satisfy the conditions for the theoretical results to hold.[28] Aligned with that prediction, we observe that no statistically significant difference exists between the subjects' payoffs in I-RM and S-CT (MWU, $p = 0.331$). We proceed by separately examining (i) how frequently the efficient effort is chosen; (ii) whether subjects fully coordinate. In Figure 4a, we see that subjects choose the efficient effort more frequently in RM than in I-RM. In some rounds, subjects choose the efficient effort more frequently in I-RM than in S-CT

[28] We numerically explore the frequency and time interval relationship in detail in Appendix C. In particular, see Figure 7 for numerical solutions.

and R-CT. In Figure 4b, we see that the number of groups that fully coordinate is similar in I-RM and the cheap-talk treatments. Based on the evidence, we conclude that gradual commitment is needed for players to coordinate on efficient equilibrium. When the commitment is less gradual, players cannot communicate and, thus, miscoordinate more often. Next, we examine how commitment affects communication directly.

5.3 How commitment affects communication

In this section, we analyze how subjects communicate over time. The introduction of commitment affects communication in two interconnected ways. First, commitment makes communication more credible. Second, commitment changes the optimal communication.

We begin by analyzing how commitment makes communication more credible. Following the discussion in Blume (1998), we examine whether the whole group converging on a particular message profile makes that equilibrium more salient. We take the groups in which all six members were choosing the same effort level by the 30th second in a given round.[29] These groups converged on a particular message (not necessarily the Pareto-optimal profile) in that round, as members are stating an intention to choose the same effort level. Now, in what fraction of these converged groups do all the group members take the same effort in the payoff-relevant moment? In RM, 87.8% of the groups that converge keep their efforts unchanged for the payoff-relevant moment, but for the R-CT, only 40.6% do so. This stark difference highlights that even when a particular equilibrium is salient—all group members choose the same message—messages are less credible in R-CT than in RM.

Next, we consider how commitment affects optimal communication. In Figure 5, we display the average equilibrium deviation of the posted efforts (Figure 5a) and of the chosen efforts (Figure 5b) over the entire 60-second interval.[30] In both graphs, in RM, we see a clear decline in the equilibrium deviation over time, as players coordinate more. More importantly, we see a drastic decline as the deadline approaches in RM. However, in the absence of commitment, no observable deadline effect exists. The difference in pattern as the deadline approaches highlights the distinct communication pattern in both treatments. Facing a group member who is choosing a smaller effort close to the deadline, a subject

[29] For the revision mechanism, in 61.3% of the rounds, the group coordinates on the same effort by the 30th second, while that number is 46.3% for the revision cheap talk.

[30] In Figure 5, we use only the last five of the total ten rounds. In Appendix H, we present the graph for all ten rounds (Figure 11).

reduces her chosen effort (thus reducing the equilibrium deviation) in RM, but not in R-CT. In the absence of commitment, lowering the choice of effort is unnecessary because revising it in the final instant is possible. This end-of-phase difference has consequences for the credibility of the messages sent.

(a) Eq. Deviation of the revised efforts (b) Eq. Deviation of the chosen efforts

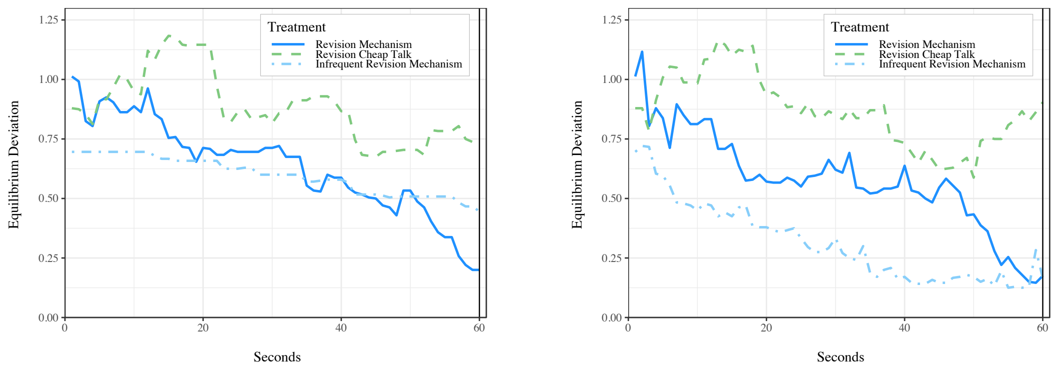

Figure 5: Equilibrium Deviation over Time

The difference between the graphs in Figures 5a and 5b is more apparent when we focus on I-RM treatment. Recall that subjects revise their effort choices only when they have a revision opportunity; however, we collect their intended effort choices even when they cannot revise. In Figure 5a, we see their actual posted effort, which changes only when a revision opportunity arrives, whereas, in Figure 5b, we see their intentions, which they can change instantaneously. For I-RM, the difference is clear. The equilibrium deviation of the effort choices is relatively flat, but a sharp decrease occurs over time when we look at the intended efforts. The subjects want to coordinate, but the absence of revision opportunities prevents them from doing so. The differences between the two graphs highlight the importance of gradual commitment to provide subjects with enough communication opportunities for them to coordinate.

5.4 Random Beginnings (Robustness of the Theory)

We now examine an additional theoretical prediction and use it as a test of the main results. According to the theory discussed in Section 3.3, if the initial choices for the players are picked at random, with a long-enough pre-play phase, we should observe the same outcome as with endogenous initial choice with probability close to 1. This prediction provides a nice robustness check of our main treatment. Moreover, R-RM treatment creates a variance in the initial choice that we lack in the revision mechanism because 86% of all initial choices are the efficient effort, 7.[31] This treatment allows us to observe the dynamic best-response behavior of our subjects and to look deeper into the fundamental forces behind Proposition 1. Proposition 1 relies on a subgame perfection argument: early in the pre-play phase, a player will choose higher efforts (even if others are not doing so, and, thus, it would be myopically suboptimal) to initiate a chain reaction leading all to choose the efficient effort.

RM and R-RM treatments lead to similar behavior in all dimensions. We find no statistically significant difference in efficiency, with R-RM achieving 78% efficiency, 2% lower than RM. Not only is the average payoff similar (10.62 versus 10.43), but the average minimum effort (5.64 vs. 5.54), the average frequency of efficient effort (0.74 vs. 0.71), and the average number of fully coordinated groups (5 vs. 4.8) are both statistically and economically indistinguishable.[32]

Classification of Dynamic Behavior We look at subjects' behavior dynamics and classify all the moves into five categories. We display in Figure 6 the types of moves taken as a function of time passed in the pre-play phase.

(i) **Forward-Thinking:** moves that would decrease the player's payoff if it were the last instant; however, these moves will increase the payoff if other players follow. This category combines two types of moves: (1) the subject's current choice is above the group's minimum, but she still increases her chosen effort; and (2) the subject's choice is the group's minimum, and she increases her effort above the second minimum action.

(ii) **Myopic Up:** moves increasing the player's effort level that would increase the payoff of the player if it were the last instant. This category contains the subject's moves when the subject is the group's minimum, and she moves up to the second minimum choice.

(iii) **Myopic Down:** moves decreasing the player's effort that would increase her payoff if it were the last instant. This category contains the subject's moves when she decreases her

[31] In the R-RM treatment, the initial effort was determined at random. On average over rounds, of the initial efforts, 7% were 1, 13% 2, 25% 3, 13% 4, 18% 5, 13% 6, and 10% 7. It is clear that this is a very different pattern from the initial choices of RM. In RM, the distribution of the initial choices were as follows: 2% were 1, 1% 2, 1% 3, 1% 4, 4% 5, 5% 6, and 86% 7.

[32] We cannot reject an MWU test of equal distributions of subjects' payoffs and minimum effort ($p = 0.187$ and $p = 0.615$, respectively).

effort choice, moving closer to the group minimum.

(iv) **Punishment:** moves decreasing the player's effort, below the group's current minimum. This type of move would be costly if it were the last instant, as it would result in a lower payoff than from the move simply matching the group's minimum—as in (iii).

(v) **Other:** moves not included in the above categories. This category contains moves when the subject decreases her effort choice, which could decrease the subject's payoff because she is already at the group minimum.

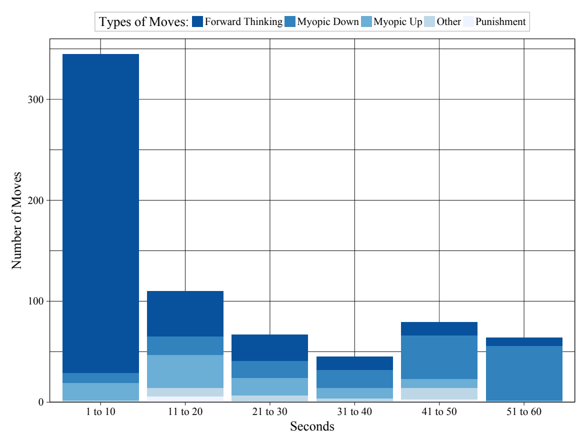

Figure 6: Classification of Moves over Time

First note, in Figure 6, that players consistently use revisions to communicate strategies and to influence other players' behavior. This communication is more important early in the round. Although players have about the same number of revision opportunities earlier or later in the round, they utilize the earlier revisions more frequently. In the first ten seconds of the round, players used more revision opportunities than in the last 50 seconds.

The primary way in which players communicate through revisions is to use forward-thinking moves—myopically suboptimal increases in effort levels. These revisions would increase a player's payoff only if other players also increase their effort levels by the end of the countdown.[33] The argument behind Proposition 1 predicts that the type of move would

[33] This idea of communicating intentions is similar to the concept of teaching other players how to play. Hyndman et al. (2012) study the influence of "teachers" in leading to Nash play.

be different if the revision opportunity were far from or near the deadline. As we verify in Appendix C, when far from the deadline, a player should revise her effort choice toward the maximum effort, 7, independent of what the other players choose. Although myopically suboptimal, this increase of effort is optimal, as it induces a cascade effect leading all players to choose 7. However, if a revision opportunity arrives close to the deadline, the player should revise her effort to the current minimum effort. When the subjects are far from the deadline, the forward-thinking moves are predominant, while myopic down moves are dominant when the deadline is looming. In the first ten seconds of a round, more than 300 revision opportunities were used for forward-thinking moves, representing around 92% of all the revision opportunities taken. In the last ten seconds, about 85% of the taken revision opportunities were used for myopic down moves. We interpret these results as evidence that subjects' dynamic behavior is consistent with the theoretical predictions, and that their behavior is firmly aligned with the forces behind Proposition 1.

6 Concluding Remarks

Coordination environments are common in real-world situations, and coordination failures leading to inefficiencies are prevalent. In this paper, we provide experimental evidence that in a particular coordination game—the minimum-effort game—commitment-enhanced communication can reduce the efficiency loss significantly more than communication alone can.

The widespread inefficiencies in minimum-effort coordination games have a particular source. In contrast to other strategic environments, in minimum-effort coordination games, all players' interests are aligned— i.e., all players agree on what is the best outcome. Inefficiencies arise due to strategic uncertainty. Our results show that institutions combining pre-play communication with incremental commitment are effective at reducing strategic uncertainty and improving players' payoffs, restoring a significant share of the efficiency loss. Theoretically, from a particular player's perspective, when incremental commitment is present, other players' communications are more likely to be their final choices. Thus, communication gains credibility and influence. Of course, all other players anticipate that influence and change their behavior accordingly. We show that institutions combining both features change the way that subjects communicate and also affect how a subject is influenced by others' communication and increases efficiency.

From an institutional design perspective, our results shed light on which features are vital in reducing strategic uncertainty and increasing efficiency, bringing incremental commitment into the spotlight. The evidence presented in Section 5.4 highlights that players' dynamic behavior is closely aligned with the theoretical predictions, leading us to conclude that the theoretically identified forces drive the efficiency gains from the revision mechanism. Although our experimental tests are restricted to a particular coordination environment, the theoretical predictions extend to a larger domain of strategic interactions, as the generality of Proposition 1 highlights.

Incremental commitment in our institution captures the intuition that changing a prepared action is harder (or more costly) when closer to the deadline for implementing the prepared action, a condition present in many real-world strategic environments. Even absent formal commitment, social relationships often display similar features. For instance, when two parents arrange that one of them will pick up the kids from school on a given Wednesday, changing that plan is easier with more advance notice. The same applies to coworkers rescheduling a meeting or canceling a commitment. Common to these examples is that agents have to prepare their actions and announce their intentions in a coordination environment, and the relationship itself provides agents with incremental commitment through the increasing cost of revising.

Our experimental results shed light on a road by which subjects achieve a more efficient outcome; on how institutions help agents coordinate their actions and reach higher payoffs, and on the features that are key to the mechanism's success. In particular, we highlight the importance of combining communication and incremental commitment. We hypothesized that the existence of commitment, even in limited form, makes the communication more credible, which reduces strategic uncertainty. This hypothesis is supported by the results, indicating that the credibility of communication is the driving force in lowering coordination failures and aiding higher payoff for all sides involved.

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A Proof of the Main Result

We first state Theorem 2 from Calcagno et al. (2014). Then, we proceed by adapting the statement to focus on the symmetric asynchronous revision game. An asynchronous revision game is symmetric if the arrival rate of the revision opportunities is the same for all players, $\lambda_i = \lambda$. The rate of revision opportunities to player i in a symmetric asynchronous revision game is $r_i = \lambda_i / \sum_{j \in I} \lambda_j = 1/n, \forall i$.

Theorem 2 (Theorem 2 in Calcagno et al. (2014))
Suppose that a common interest game is a K-coordination game with the strict Pareto-dominant action profile $\bar{e}$, and

$$\left(1 - \min_{j \in I} r_j - \min_{\substack{i \in I \\ i \neq j}} r_i\right) K < 1 - \min_{\substack{i \in I \\ i \neq j}} r_i.$$

Then, for any $\varepsilon > 0$, there exists T' such that for all $T > T'$, in all revision equilibria, $e_0 = \bar{e}$ with probability higher than $1 - \varepsilon$.

Let us rewrite the condition for the proof, taking into account that in a symmetric revision game, $r_i = 1/n, \forall i$. Thus, the condition becomes

$$n - 1 > K(n - 2),$$

as we have in Proposition 1.

B Discrete-Time Asynchronous Revision Game

B.1 Model

We change the model presented in the main text in two ways. First, we consider discrete instead of continuous time in the pre-play phase. Second, we accommodate non-independent random revision opportunities, maintaining the asynchronicity of the revisions, in line with the experimental approach.

As in the main model, we consider a normal-form game with n players each one can take an action $e_i \in E$, and players' payoffs are characterized by $\{u_i(e_1, e_2, ..., e_n)\}_{i \in I} =$

$\gamma + \alpha \min_{j \in I} e_j - \beta e_i$. Before players actually take actions, they need to prepare their actions. We depart from the main model in that time is discrete, $-t \in \{-T, -(T-1), ..., -1, 0\}$. The normal-form game described above (the component game) is played once and for all at time 0. The game proceeds as follows. At time $-T$, a profile of actions is prepared (either exogenously given or simultaneously and independently chosen by the players) and the pre-play phase begins. Between time $-T$ and 0, at each time, a revision opportunity is awarded to the group with probability p. A revision opportunity awarded to the group is allocated to one member of the group with equal probability; thus, the rate of revision opportunities is the same for all players, $r_i = r = \frac{1}{n}$. Players can revise their prepared actions only when they have a revision opportunity. At $t = 0$, the action profile that has been most recently prepared is taken, and each player receives the corresponding payoff, as dictated by the component game, given profile $\mathbf{e}(0)$.

B.2 Result

Proposition 2 *In an asynchronous revision game with symmetric arrival rate of revision opportunities, if the component game is a K-coordination game with the strict Pareto-dominant action profile, $\bar{\mathbf{e}}$, and the game satisfies $(n-2)K < (n-1)$, then for any $\varepsilon > 0$, there exists $T' > 0$ such that for all $T > T'$, all revision equilibria have $\mathbf{e}(\mathbf{0}) = \bar{\mathbf{e}}$ with probability higher than $1 - \varepsilon$.*

Similar to the proof in Calcagno et al. (2014), ours relies on a backward-induction argument. In the first step of the proof, we show that the Pareto-dominant equilibrium profile $\bar{\mathbf{e}}$ is absorbing in the revision game. If all players choose the maximal effort, then, for any subgame following that, the unique subgame perfect equilibrium is for all players to play $\bar{\mathbf{e}}$. More formally, we show that, at a certain period, it is true that if all other players are preparing $\bar{e}_{-i}$, player i will prepare $\bar{e}_i$ if she has a revision opportunity. In the period immediately before, if all other players are preparing $\bar{e}_{-i}$, player i will prepare $\bar{e}_i$ if she has a revision opportunity. In the main proof, this argument was convoluted because backward induction in continuous time is not trivial, given that we now consider discrete time this step is simplified.

If only two players were present, this would constitute the whole argument, because a player would always be in the position to induce the other player to prepare the maximum effort. However, $n > 2$ complicates the matter, as the unraveling argument is not trivial. We show that the condition $(n-2)K < (n-1)$ is sufficient to have a lower bound on players' payoff of choosing the efficient action converge to the efficient payoff. Thus, at the end of the countdown, all players prepare the maximal effort with probability $1-\varepsilon$.

Before we proceed to the formal proof, let us once more highlight that—as in the main model—the condition in Proposition 2 is sufficient but not necessary. We discuss this further in Appendix C.

Proof. Let $\underline{\mathrm{v}}_i^t(k)$ be the infimum of player i's payoff at t in subgame perfect equilibrium strategies and histories such that there are at least k players who prepare the action $\bar{\mathbf{e}}$, and no player receives a revision opportunity at t. By mathematical induction with respect to $k = n, n-1, ..., 0$, we show that $\lim_{t\to-\infty} \underline{\mathrm{v}}_i^t(k) = \pi_i(\bar{\mathbf{e}}), \forall i$. Step 1 below shows the proof for $k = n$.

Step 1 Consider the final period. All $-i$ players are preparing the profile $\bar{e}_{-i}$ and i has a revision opportunity. It is optimal for player i to prepare $\bar{e}_i$, as this leads to a higher payoff than any other possible effort choice ($\bar{\mathbf{e}}$ is the Pareto-dominant profile and is an equilibrium).

Now, for the inductive step, consider any period τ after t. If all $-i$ players are preparing the profile $\bar{e}_{-i}$ and i has a revision opportunity, it is optimal for player i to prepare $\bar{e}_i$. Consider also that, at the period immediately before t, $t-1$, all $-i$ players are preparing the profile $\bar{e}_{-i}$ and i has a revision opportunity. If player i prepares $\bar{e}$, then she guarantees herself payoff $\pi_i(\bar{\mathbf{e}})$. If player i prepares any other action e, her expected payoff can be bounded by $(1-(1-\frac{p}{n})^{-t})\pi_i(\bar{\mathbf{e}}) + (1-\frac{p}{n})^{-t}(\pi_i(\bar{\mathbf{e}}) - \alpha) < \pi_i(\bar{\mathbf{e}})\ \forall t$, where the bound is obtained by considering that (i) $\pi_i(\bar{\mathbf{e}}) - \alpha$ is the second-best payoff for player i, (ii) with probability $(1-\frac{p}{n})^{-t}$ player i gets no revision opportunity before the deadline, and (iii) all other players continue to exert maximal effort. This concludes step 1.

Step 2 (inductive argument) Suppose that $\lim_{t\to-\infty} \underline{\mathrm{v}}_i^t(k+1) = \pi_i(\bar{\mathbf{e}}),\ \forall i$, with $k+1 \leq n$, we will show that $\lim_{t\to-\infty} \underline{\mathrm{v}}_i^t(k) = \pi_i(\bar{\mathbf{e}}),\ \forall i$.

Consider an arbitrary $\varepsilon > 0$. Since $\lim_{t\to-\infty} \underline{\mathrm{v}}_i^t(k+1) = \pi_i(\bar{\mathbf{e}}),\ \forall i$, it must be that there exists a finite T_0 such that $\forall t \leq T_0$, $\underline{\mathrm{v}}_i^t(k+1) \geq \pi_i(\bar{\mathbf{e}}) - \varepsilon\ \forall i$. Consider that k players prepare $\bar{\mathbf{e}}$ at a time t before the said T_0, that is $t = T_0 + \tau_1$ with $\tau_1 \leq 0$. Then, if player j who is not preparing $\bar{\mathbf{e}}$ at time t can move first by T_0, she yields at least $\pi_j(\bar{\mathbf{e}}) - \varepsilon$ by preparing $\bar{e}_j$. This implies each player i will at least yield $\pi_i(\bar{\mathbf{e}}) - K\varepsilon$. Therefore, we can define a lower bound for a player's utility if k players are preparing $\bar{\mathbf{e}}$ at time t:

$$\underline{v}_i^t(k) \geq \frac{1}{n}(1-(1-p)^{\tau_1})(\pi_i(\bar{\mathbf{e}}) - K\varepsilon) + (1 - \frac{1}{n}(1-(1-p)^{\tau_1}))\underline{\pi_i(e)}\ \forall i,$$

where $\frac{1}{n}(1-(1-p)^{\tau_1})$ is the probability that there is a revision and a particular player j who is not preparing $\bar{e}$ at that time is the first to get a revision before time T_0. We also assume that if such a move does not occur, the worst possible payoff will happen.

If τ_1 is a time interval sufficiently long, then there exists finite T_1 such that for all $\tau_2 \leq 0$, if the period is far removed from the deadline; $t = T_0 + T_1 + \tau_2 \leq T_0 + T_1$, then $\underline{v}_i^t(k) \geq \frac{1}{n}\overline{\pi_i(e)} + (1-\frac{1}{n})\underline{\pi_i(e)} - K\varepsilon\ \forall i$. Introducing a bit of notation, we can define $\alpha_1 = \frac{1}{n}$, and $\underline{v}_i^t(k) \geq \alpha_1\pi_i(\bar{\mathbf{e}}) + (1-\alpha_1)\underline{\pi_i(e)} - K\varepsilon\ \forall i$

For $t = T_0 + T_1 + \tau_2$ we can find a lower bound on player's payoff $\underline{v}_i^t(k)$ in different cases:

1. If j moves first by $T_0 + T_1$, then a lower bound on player $i's$ payoff depends on whether or not j is preparing $\bar{e}_j$.

   - If j is not preparing $\bar{e}_j$ at time t, then a lower bound on player $i's$ payoff is $\pi_i(\bar{\mathbf{e}}) - K\varepsilon$ as before.
   - If j is preparing $\bar{e}_j$ at time t she will move first by $T_0 + T_1$; then, a lower bound on player $j's$ payoff is given by $\frac{1}{n}\pi_j(\bar{\mathbf{e}}) + (1-\frac{1}{n})\underline{\pi_j(e)} - K\varepsilon$ by the same reasoning as before. This implies that for player i, a lower bound on her payoff is given by $(1 - K(1-\frac{1}{n}))\pi_i(\bar{\mathbf{e}}) + K(1-\frac{1}{n})\underline{\pi_i(e)} - K^3\varepsilon$.

2. If i herself will move first by $T_0 + T_1$, then a lower bound depends on whether or not she is herself preparing $\bar{e}_i$.

   - If she is one of the k preparing $\bar{e}$, then a lower bound is given by $\frac{1}{n}\pi_i(\bar{\mathbf{e}}) + (1 - \frac{1}{n})\underline{\pi_i(e)} - K\varepsilon$.
   - If she is not one of the k preparing $\bar{e}$, by doing a revision, she can guarantee, by the inductive hypothesis, at least $\pi_i(\bar{\mathbf{e}}) - \varepsilon$.

In total, player i's payoff satisfies:

$$\begin{aligned}\underline{\mathrm{v}}_i^t(k) &\geq \tfrac{1}{n}(1-(1-p)^{\tau_2})(\pi_i(\bar{\mathbf{e}})-K\varepsilon)\\&+(\tfrac{1}{n}(1-(1-p)^{\tau_2})+(1-p)^{\tau_2})(\tfrac{1}{n}\pi_i(\bar{\mathbf{e}})+(1-\tfrac{1}{n})\underline{\pi_i(e)}-K\varepsilon)\\&+(1-\tfrac{2}{n})((1-(1-p)^{\tau_2}))(1-K(1-\tfrac{1}{n}))\pi_i(\bar{\mathbf{e}})+K(1-\tfrac{1}{n})\underline{\pi_i(e)}-K^3\varepsilon),\ \forall i\end{aligned}$$

Taking a sufficiently long τ_2, there exists a finite T_2 such that at $t = T_0 + T_1 + T_2 + \tau_3$ with $\tau_3 \leq 0$, we have that

$$\begin{aligned}\underline{\mathrm{v}}_i^t(k) &\geq (\tfrac{1}{n}+\tfrac{1}{n^2}+(1-\tfrac{2}{n})(1-K(1-\tfrac{1}{n})))\pi_i(\bar{\mathbf{e}})\\&+(1-\tfrac{1}{n}+\tfrac{1}{n^2}+(1-\tfrac{2}{n})(1-K(1-\tfrac{1}{n})))\underline{\pi_i(e)}-K^3\varepsilon,\ \forall i\end{aligned}$$

defining $\alpha_2 = \frac{1}{n}+\frac{1}{n^2}+(1-\frac{2}{n})(1-K(1-\frac{1}{n}))$, we have the second step $\underline{\mathrm{v}}_i^t(k) \geq \alpha_2\pi_i(\bar{\mathbf{e}}) + (1-\alpha_2)\underline{\pi_i(e)} - K^3\varepsilon\ \forall i$.

Recursively, for each $M = 1, 2, ...$, there exists $T_0, T_1, ...$ such that $t \leq T_0+T_1+...+T_M$,

$$\underline{\mathrm{v}}_i^t(k) \geq \alpha_M\pi_i(\bar{\mathbf{e}}) + (1-\alpha_M)\underline{\pi_i(e)} - K^{2M-1}3\varepsilon\ \forall i.$$

with $\alpha_M = \frac{1}{n}+\frac{1}{n}\alpha_{M-1}+(1-\frac{2}{n})(1-K(1-\alpha_{M-1}))$.

The condition in Proposition 2 is sufficient to guarantee that α_M is monotonically increasing and converges to 1. Taking a large enough T yields the result. ■

C Numerical Solution of the Discrete Time Revision Game

In this section, we explain the backward-induction procedure to solve the game for the specific parameters given in our experiment. We consider a particular payoff specification following our experimental setup: a triple of linear coefficients $\gamma,\ \alpha,\ \beta$, a given number of players n, a given set of actions E, a pre-play length T, and a given revision probability, p. We solve the game for the expected payoff of every player at any time $-t \in \{-T, -(T-1), ..., -1, 0\}$, for every strategy profile. We also obtain the transition probability from any strategy profile to any other strategy profile between any two periods.

At the deadline ($t = 0$): We construct an n-tuple vector with dimension $|E|^n$, called V_0. Each line of V_0 has the payoff of each player if a particular strategy profile, e, is played.

Before the deadline, $t \in [-T, 0)$**:** Consider a given vector V_{t+1}. An n-tuple of V_{t+1} has the expected payoff of all players at time $t+1$ if that particular strategy profile is prepared (given that all players maximize their payoff if they have a revision in the future). We proceed backwards inductively, given the vector V_{t+1}, we construct V_t in the following way. First, for any strategy profile, we can compute how a player would revise her effort choice. That is if player i had a revision opportunity which effort would she choose, given that her expected payoffs of different action profiles are given by the vector V_{t+1}. This gives us the auxiliary matrix V_t^{rev}, a $|E|^n \times n$ matrix of n-tuples. Each element of the matrix gives us the payoff of all players if the strategy line were in place, and the player column had a revision opportunity at time t. The vector V_t is obtained by $(1-p) \times V_{t+1} + \frac{p}{n} \times V_t^{rev} \times \mathbf{1}_{n \times 1}$, where the first term is obtained when no one has a revision (and, thus, the strategy profile is unchanged), and the second term is the expected value of the payoff for each player given that someone has received a revision opportunity. We can iterate this process until V_{-T}.

Using the numerical solution to verify the proposition: For a particular set of parameters, $\gamma,\ \alpha,\ \beta,\ n,\ |E|,\ T,\ p$, we say that Proposition 1 holds if, for a finite $\bar{T}(\gamma,\ \alpha,\ \beta,\ n,\ |E|,\ p) < T$, when a player has a revision opportunity, she chooses $\bar{e}_i$ independent of the effort profile in place. That is, for all $t > \bar{T}$, playing $\bar{e}_i$ dominates any other effort choice, and all elements of the matrix V_t^{rev} are equal to $\pi_i(\bar{\mathrm{e}})$. For the first part of Proposition 1, note that for any given $\varepsilon > 0$, if $T' \geq \bar{T} + \tau$, then the profile $\bar{\mathrm{e}}$ is played with probability larger than $1-\varepsilon$. The integer τ is defined as the minimum interval of time such that the probability that all players have at least one revision opportunity in that interval is larger than $1-\varepsilon$; that is, τ is the smaller integer that solves $\left(1-(1-\frac{p}{n})^\tau\right)^n \leq 1-\varepsilon$. We can see that the time interval needed, τ, increases with the number of players and decreases with the probability of a revision being awarded. For the second part of Proposition 1, it is sufficient that $T' \geq \bar{T}$. Note that the condition specified on the Propositions is sufficient, but not necessary for the particular payoff parameters used in this paper.

Going beyond the proposition: As a byproduct of the construction of V_t from V_{t+1}, we also obtain a transition matrix, M_t, with dimensions $|E|^n \times |E|^n$, that specifies for any strategy profile today the probability that, in the next period, each profile will be chosen. For any given set of parameters, given a distribution of effort profiles at time $-T$, $e(-T)$, we can calculate the final distribution of efforts, at time 0, for any length of the pre-play phase,

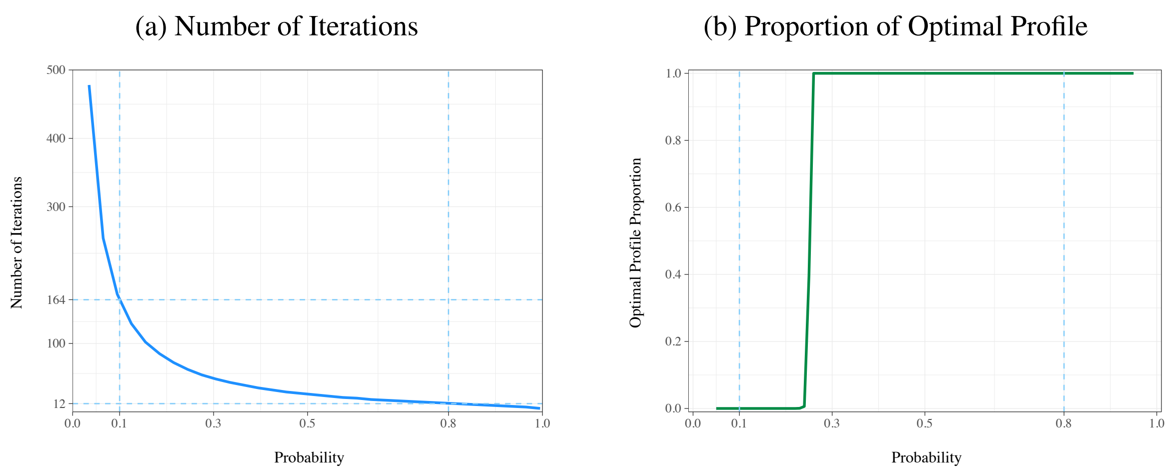


Figure 7: Numerical Solution Outputs

$e(-T) \times \prod_{s=-T}^{0} M_s$.

The two plots in Figure 7 highlight how the probability of a revision, p, changes the expected results of the game. We focus on two key dimensions: (i) the number of periods needed for $\bar{e}$ to be the dominant effort choice independent of the profile in place, $\bar{T}$; and (ii) the probability of the profile $\bar{\mathbf{e}}$ being chosen at the end of the countdown, given that $T = 60$ and the game was started with a profile chosen at random.

D Typology of Moves

In subsection 5.4, we classify revisions in various categories and identify the use of the pre-play phase as a communication device; and as an important element on how players coordinate. We now further investigate the revision process, by looking at whether players assume distinct roles within the groups, that is, whether forward-thinking revisions are usually made by the same subgroup of players.

Although, on average, each subject used about six revisions in the revision mechanism treatment, the median number of revisions is three. In Figure 8a, we display the number of revisions each player has taken, and classify those revisions according to the same criteria used in subsection 5.4: a revision move may be forward-thinking, myopic up, myopic down, punishment, or other.

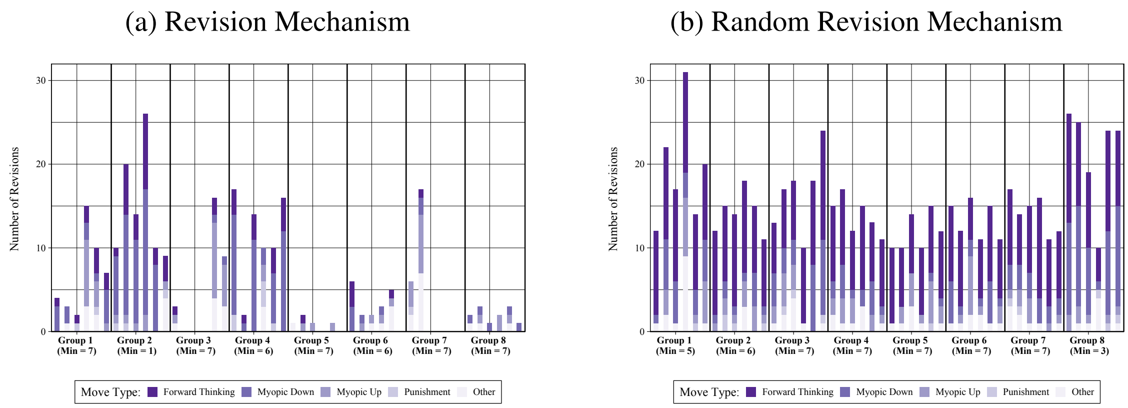


Figure 8: Revision Typology

Figure 8a shows that one-sixth of our subjects have never changed their action even once, and half of the subjects made less than 5 revisions. Nevertheless, some subjects made more than 15 revisions, and, in particular, one of them revised the action as many as 28 times. Note that members of Group 2, which coordinated on the payoff worst equilibrium, are well above the average and each used more than 10 revisions.

As we classify each player's revision moves, Figure 8 indicates that players distribution of revision moves across those categories is quite similar. This observation indicates that players do not assume fixed roles within each group—one player as the forward-thinking, another as a follower, and so on. Instead, they all try to communicate their intentions through forward-thinker, and they all use the other types of revisions in similar proportions.

Figure 8b presents the same revision classification by subject for the random-initial-choice treatment. As expected, each subject uses more revisions in RRM beacuse the initial choice is randomly assigned to them each round. On average, each subject used about 15 revisions in random-revision mechanism, with the median number of revisions at 16.

E Choice vs Posted Effort

In our paper, actions can be changed only when a revision opportunity is awarded; thus, in any instant, two different data points exist per player: (i) the effort the player is currently committed to, which all the other players are observing; and (ii) the effort currently selected by the player. Only after a revision opportunity is awarded can the selected effort choice become the effort to which the player is committed.

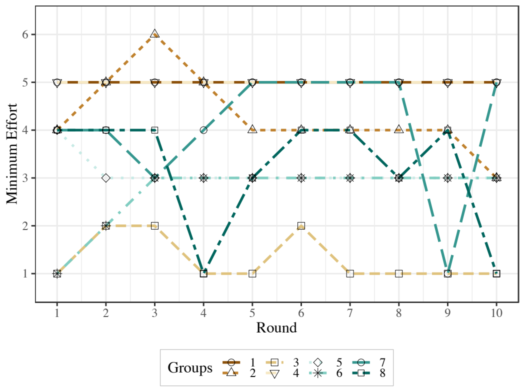
Let us evaluate the robustness of our experimental design by examining whether our choices of the time-interval length and the revision probability had an impact on the choices. We therefore compare the last-instant intended efforts with the efforts played out. If the time interval were too short, or revisions too infrequent, the players' intended actions would be different than the posted actions, even in the last instant, and subjects would have been constrained in their choice process. However, we cannot reject the hypothesis of equal distributions of actions ($p > 0.1$), which indicates the choice of interval length and revision frequency did not bind players' behaviors, thus aligning our experimental design with the conditions of the main Proposition.

F Group Level Data

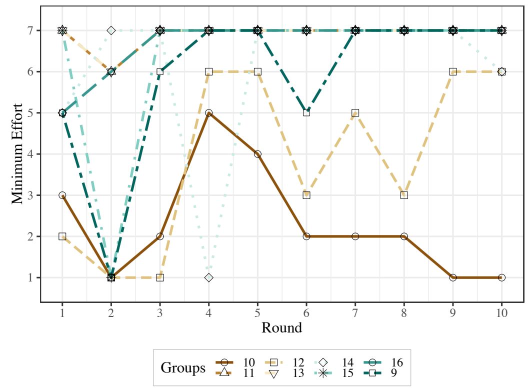
For all groups in each treatment we calculate the minimum effort in every round and display the results in Figure 9. As we have seen from the aggregate results in Figure 9, the groups in the revision mechanism treatment stabilize and achieve higher effort levels than those in the baseline and cheap-talk treatments (S-CT and R-CT).

Figure 9: Group Minimums in Each Treatment

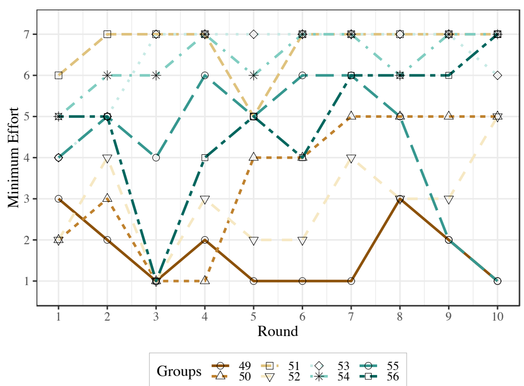
(a) Baseline Treatment



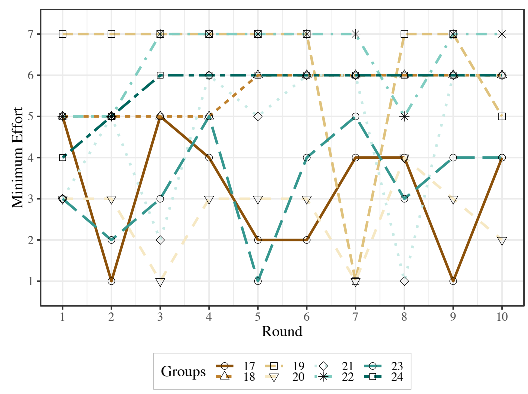
(b) Revision Mechanism



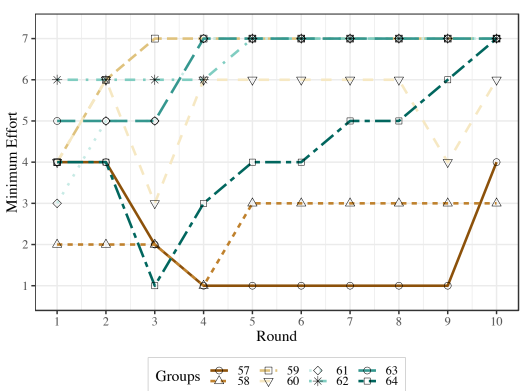
(c) Standard Cheap Talk



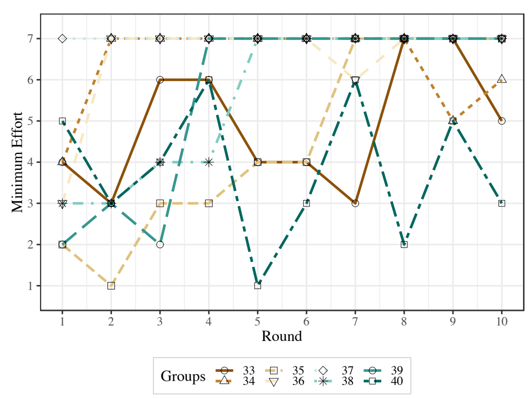
(d) Revision Cheap Talk



(e) Infrequent-Revision Mechanism



(f) Random-Revision Mechanism



G Survey Results

At the end of the experiment, our subjects took a short survey recording their gender, major, GPA, and whether they had taken a game theory course — summary is in Table 2.

Table 2: Survey Results

Variable:	%/pt
Gender	52.97619
Game Theory	22.32143
GPA	3.470181
Major: Economics	18.45238
Major: Humanities	13.39286
Major: CS	11.60714
Major: Media	8.630952
Major: Psychology	5.952381
Major: Engineering	5.357143
Major: Math	4.464286
Major: Physics/Chemistry	2.380952

H Additional Tables and Figures

Figure 10 presents the empirical CDFs of subjects' payoffs for three main treatments in the paper. We observe a clear first-order dominance of the revision mechanism over both the baseline and S-CT treatments. A Mann-Whitney U test of equal distributions is rejected at $p < 0.01$.

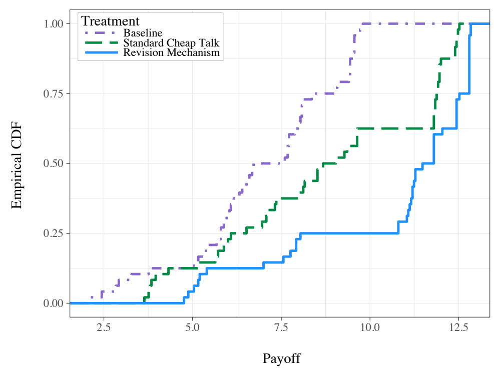


Figure 10: Empirical CDFs

In Figure 11, we display the average of 10 rounds of equilibrium deviation of the posted efforts and of the chosen efforts over the entire 60-second interval.

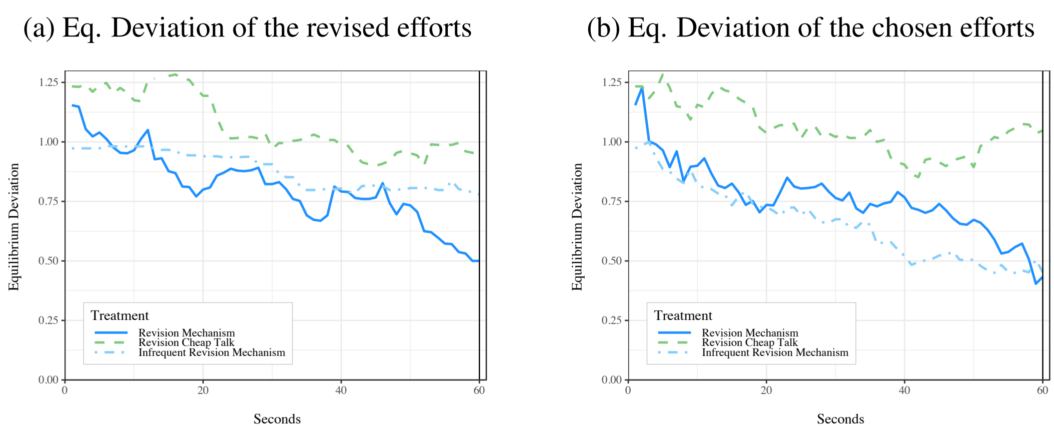


Figure 11: Equilibrium Deviation over Time (all 10 rounds)

Table 3 presents the results of a regression with the relevant dependent variables identified in the results section. We don't find a significant effect of gender or game theory course taken on the dependent variables, and the treatment variable confirms the direction showed in the results section.

Table 3: Regression Analysis

	Dependent variable:			
	Payoffs	*Minimum Effort*	*Freq Efficient Effort*	*Eqbm Deviation*
Revision Mechanism	3.570***	2.050***	0.475***	−0.985***
	(0.527)	(0.701)	(0.119)	(0.217)
Random-Revision Mechanism	3.380***	1.950***	0.444***	−0.908***
	(0.534)	(0.561)	(0.100)	(0.225)
Infrequent-Revision Mechanism	2.420***	1.400*	0.302**	−0.696**
	(0.530)	(0.757)	(0.120)	(0.293)
Standard Cheap Talk	1.750***	1.020	0.173	−0.625**
	(0.537)	(0.748)	(0.125)	(0.270)
Revision Cheap Talk	1.810***	1.120*	0.281**	−0.319
	(0.529)	(0.653)	(0.110)	(0.254)
Demographics	Yes	NA	NA	NA
Constant	5.750***	3.590***	0.269***	1.490***
	(1.160)	(0.424)	(0.031)	(0.181)
Observations	288	480	480	480
R^2	0.196	0.113	0.176	0.109
Coefficient test (p-value)				
RMs vs CTs	0.057	0.074	0.035	0.004

Note: *Standard errors clustered at the group level are in parentheses; *p <0.1; **p <0.05; ***p <0.01; Coefficient tests are done with standard errors clustered at the group level.*

Table 4: Regression with Rounds

	Dependent variable:		
	Minimum Effort	*Freq Efficient Effort*	*Eqbm Deviation*
Round	-0.034	-0.046^{***}	-0.140^{**}
	(0.034)	(0.009)	(0.059)
Infrequent Revision Mechanism	0.183	-0.126	-0.779
	(0.714)	(0.119)	(0.481)
Random Revision Mechanism	0.250	0.018	-0.881
	(0.870)	(0.138)	(0.535)
Revision Cheap Talk	0.617	0.076	-0.825^{*}
	(0.728)	(0.130)	(0.473)
Revision Mechanism	0.958	0.137	-1.080^{**}
	(0.775)	(0.118)	(0.456)
Standard Cheap Talk	0.100	-0.139	-0.926^{*}
	(0.851)	(0.110)	(0.488)
Round × Infrequent Revision Mechanism	0.221^{***}	0.078^{***}	0.015
	(0.068)	(0.015)	(0.065)
Round × Random Revision Mechanism	0.309^{***}	0.077^{***}	-0.005
	(0.108)	(0.017)	(0.075)
Round × Revision Cheap Talk	0.092	0.037^{***}	0.092
	(0.060)	(0.012)	(0.069)
Round × Revision Mechanism	0.198^{***}	0.061^{***}	0.017
	(0.076)	(0.013)	(0.063)
Round × Standard Cheap Talk	0.168^{**}	0.057^{***}	0.055
	(0.082)	(0.015)	(0.066)
Constant	3.770^{***}	0.524^{***}	2.260^{***}
	(0.471)	(0.068)	(0.395)
Observations	480	480	480
R^2	0.166	0.218	0.215

Note: *Standard errors clustered at the group level are in parentheses;* $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$;

Throughout the paper we use various hypotheses to test treatment effects. Table 5 provides details on the test used, the exact hypotheses as well as the score, p-value, number and unit of observations.

Table 5: Non-parametric Test Details

Test	Hypothesis	Score	p-value	N	Unit of Observation
MWU	Equal payoff distributions, S-CT vs. RM	W = 1552	0.0034	48 + 48	Subject total payoff (no show-up fee)
MWU	Equal payoff distributions, S-CT vs. R-CT	W = 1064	0.524	48 + 48	Subject total payoff (no show-up fee)
MWU	Equal payoff distributions, R-RM vs. RM	W = 1332	0.187	48 + 48	Subject total payoff (no show-up fee)
MWU	Equal payoff distributions, I-RM vs. S-CT	W = 1019	0.331	48 + 48	Subject total payoff (no show-up fee)
MWU	Equal minimum effort distributions, S-CT vs. RM	W = 4254.5	0.0002	80 + 80	Group minimum in a given round
MWU	Equal minimum effort distributions, R-CT vs. RM	W = 4363.5	0.0000	80 + 80	Group minimum in a given round
MWU	Equal minimum effort distributions, S-CT vs. R-CT	W = 3221	0.9434	80 + 80	Group minimum in a given round
MWU	Equal minimum effort distributions, RM vs. R-RM	W = 3333	0.6148	80 + 80	Group minimum in a given round
MWU	Equal effort choices distributions, S-CT vs. RM	W = 14765	0.0000	480+480	Subject effort in a round
MWU	Equal effort choices distributions, R-CT vs. RM	W = 13456	0.0000	480+480	Subject effort in a round

I Group 2 Dynamics (Coordination on Payoff-Worst)

One of the eight groups in the revision mechanism treatment diverged to choosing the payoff-worst equilibrium. To analyze the players' behavior more closely and to identify possible reasons for coordination on the payoff-worst equilibrium, we take a closer look at Group 2's effort choices and revisions over all rounds and within them. In this group, three out of six group members began every round by choosing the efficient effort and moved towards the group minimum later. Among the other three, two were responsive to the group members' efforts and revisions, and only one subject did not seem to react to the information embedded in other players' efforts. In the first round, four out of six group members initially chose the efficient effort, and the other two chose effort 3. One of two players who chose 3 moved up to 5, then 6, and the unresponsive subject stayed at 3 in spite of 8 awarded revision opportunities.

We identify the latter subject as being unresponsive to the team members' efforts and revisions. Even though the group minimum at the end of the first round was 3, this subject started the second round by choosing effort two and then switching to 1, although the minimum without this subject was 5. Moreover, in the fourth round, this group achieved the minimum effort 6, and then the unresponsive subject suddenly moved down from 6 to 4, while all other group members chose the efficient effort. The choices of the unresponsive subject seem to be the main driving force behind the group's failure to coordinate on the payoff-dominant equilibrium. This result highlights how unforgiving the minimum game is if one player chooses the lowest effort instead of the efficient one, all players' payoffs decrease. It is interesting to note, however, this particular subject did not seem to have a discouraging effect on others, as half of the group still began the last round by choosing the efficient effort and adjusted their efforts up until the end of the final one-minute countdown.

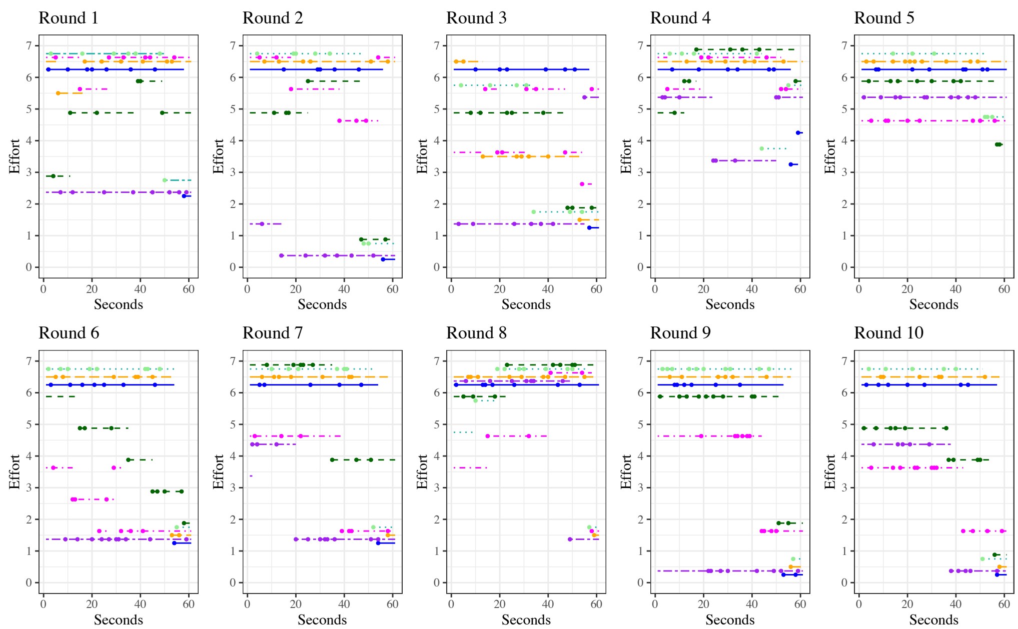


Figure 12: Group 2 Dynamics

J Instructions: Baseline

Instructions

This is an experiment in decision making. Funds have been provided to run this experiment. If you follow instructions and make good decisions you may earn a substantial amount of money, that will be paid to you in CASH VOUCHERS at the end of the experiment. What you earn depends partly on your decisions and partly on the decisions of others.

The entire session will take place through computer terminals, and all interactions between you will be done through the computers. Please, do not talk or communicate in any way during the session. Please, turn off your phones now.

You will be randomly divided in groups of **6** persons, and will make a sequence of **10** decisions as a part of that group. After 10 periods, all groups will be disband and the phase will end. This will be the end of the experiment.

Task Description

Each period, you and every member of your group will choose an integer: **1, 2, 3, 4, 5, 6 or 7**. Your choice and the smallest number chosen in your group (**including yours**) will determine your payoff in that period. Table 1 presents your payoffs in all possible scenarios. For example, if you choose number 5 and the smallest number chosen in your group is 4 you will get 78 Cents ($.78).

		Smallest Number Chosen						
		7	6	5	4	3	2	1
	7	1.30	1.10	0.90	0.70	0.50	0.30	0.10
	6	—	1.14	0.94	0.74	0.54	0.34	0.14
	5	—	—	0.98	0.78	0.58	0.38	0.18
Your Choice	4	—	—	—	0.82	0.62	0.42	0.22
	3	—	—	—	—	0.66	0.46	0.26
	2	—	—	—	—	—	0.50	0.30
	1	—	—	—	—	—	—	0.34

Table 1 – Payoff from different actions

Payoffs

Your **final payoff** will be the sum of payoffs from all 10 periods plus the show up fee.

K Instructions: Revision Mechanism

Instructions

This is an experiment in decision making. Funds have been provided to run this experiment. If you follow instructions and make good decisions you may earn a substantial amount of money, that will be paid to you in CASH VOUCHERS at the end of the experiment. What you earn depends partly on your decisions and partly on the decisions of others.

The entire session will take place through computer terminals, and all interactions between you will be done through the computers. Please, do not talk or communicate in any way during the session. Please, turn off your phones now.

You will be randomly divided in groups of **6** persons, and will make a sequence of **10** decisions as a part of that group. After 10 periods, all groups will be disband and the phase will end. This will be the end of the experiment.

Task Description

Each period, you and every member of your group will choose an integer: **1, 2, 3, 4, 5, 6 or 7**. Your choice and the smallest number chosen in your group (**including yours**) will determine your payoff in that period. Table 1 presents your payoffs in all possible scenarios. For example, if you choose number 5 and the smallest number chosen in your group is 4 you will get 78 Cents ($.78).

		Smallest Number Chosen						
		7	6	5	4	3	2	1
Your Choice	7	1.30	1.10	0.90	0.70	0.50	0.30	0.10
	6	—	1.14	0.94	0.74	0.54	0.34	0.14
	5	—	—	0.98	0.78	0.58	0.38	0.18
	4	—	—	—	0.82	0.62	0.42	0.22
	3	—	—	—	—	0.66	0.46	0.26
	2	—	—	—	—	—	0.50	0.30
	1	—	—	—	—	—	—	0.34

Table 1 – Payoff from different actions

Once you and all the members of your group have chosen a number, a 1-minute countdown will begin. Only the number posted at the end of the countdown matters for your payoff.

1-minute Countdown

1. *Graph Description*

   Before the 1-minute countdown, you and every member of your group have chosen a number: **1, 2, 3, 4, 5, 6 or 7**. Once every member of your group has made their initial choice, the 1-minute countdown begins.

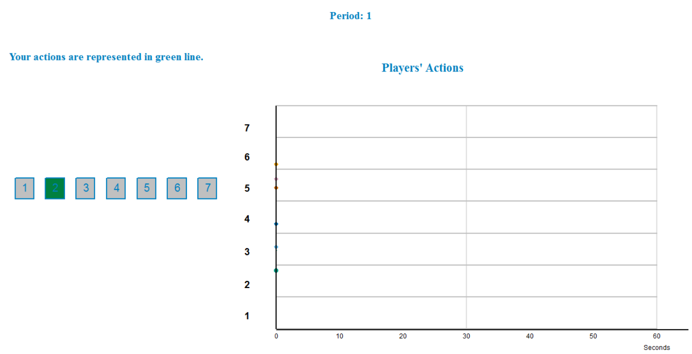
   

   Figure 1 – Screen-shot of one possible scenario, as soon as the 1-minute countdown begins.

   When the 1-minute countdown begins your screen will appear as in Figure 1. In Figure 1, we have placed time in seconds on the horizontal axes and the number chosen by each of your group members on the vertical axes.

   The initially picked numbers chosen by you and your cohort are place along the vertical line above the zero second mark. You will see the number posted of every participant in your group. For instance, in Figure 1, we see that 2 players have chosen number 5, 1 player has chosen 2, 1 player has chosen 3, 1 player has chosen 4 and 1 player has chosen 6. Your choice is always represented in the graph with the color green, and those of others by other colors. As you can see the player has CHOSEN NUMBER 2.

   As time continues, during the 1 minute, you will be able to change your chosen number at any time by placing your cursor on your desired number to the left of the screen. When you choose a number, it will light up as the number 2 now is.

2. *Revision Opportunities*

   However, the fact that you have changed your choice DOES NOT imply that the number on the graph will change. The number on the graph will only change if a **revision opportunity** is awarded to you. A revision opportunity is awarded at random times.

   Every second a revision opportunity will be awarded to the group with 80% chance. When a revision opportunity is awarded to the group, it will be given to one of the 6 group members, with equal probability of $\frac{1}{6}$. So the chance of any other member of your group having a revision opportunity and being able to change the posted number is exactly equal to yours: $p = .8 \times \frac{1}{6} \approx 13\%$.

If you had changed the number chosen, and received a revision opportunity, your number on the graph will change (the GREEN line will shift). If a revision opportunity is awarded to you, but you had not previously changed your chosen number, the number on the graph will **not** change. Let's call the number that you have chosen (the one that is lit up) which appears on the graph, your NUMBER POSTED on the graph.

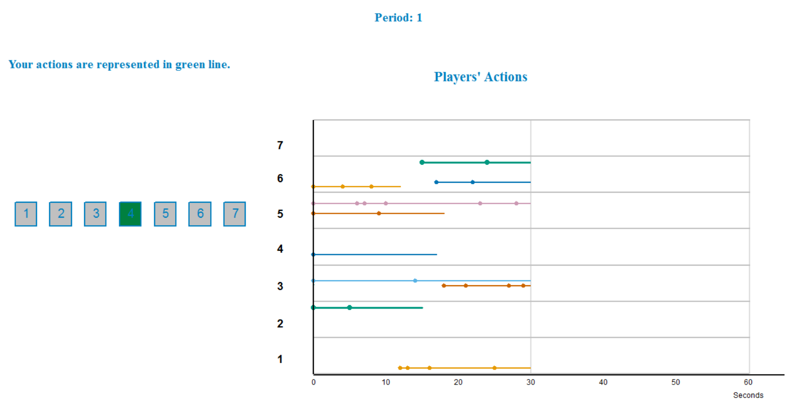


Figure 2 – Screen-shot of one possible scenario, after 1 minute has passed.

When 30 seconds have passed your screen will appear as in Figure 2. You can see how many times any member of your group changed the number posted (the line changes) as well as whether a revision opportunity was awarded (*a dot on the line*). For instance, player PURPLE has not changed the number posted (which is 5) despite having received 5 revision opportunities (5 dot's on light purple line). On the other hand, player ORANGE initially chose number 5, but after about 20 seconds the posted number became 3. Player GREEN has changed the number posted once. Let's take a closer look at player GREEN's actions:

(a) GREEN initially chose to post 2.

(b) Then, in the 4th second, a revision opportunity arrived, but the number posted by player GREEN did not change.

(c) In second 15, a revision opportunity arrived and the number posted changed to 6. Note that this was only possible because he had changed the number chosen prior to the arrival of revision opportunity.

(d) In second 25, revision opportunity arrived, but the number posted didn't change.

Finally, note that player GREEN has chosen the number 4 (it is lit up in green), but given that no revision opportunity has arrived, the NUMBER POSTED on the graph is still 6.

3. *Final Payoffs*

   At the end of the 1 minute countdown, you will receive a payoff that depends on your number posted and on the smallest number posted by a player in your group. *Only the numbers posted at the* **end** of the countdown matter for your payoff. The numbers posted before do not matter at all for your payoff. Your **final payoff** will be the sum of payoffs from all 10 periods plus the show up fee.

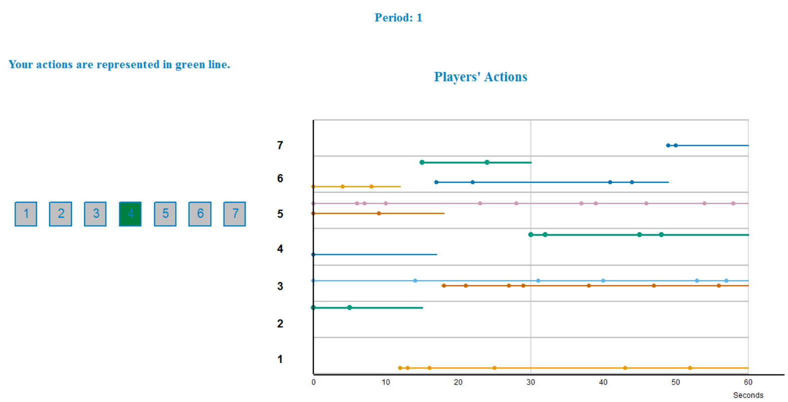


Figure 3 – Screen-shot of one possible scenario, after the 1-minute countdown has finished.

When 1-minutes have passed your screen will appear as in Figure 3. You can see the number posted of every participant in your group. Note that only the number posted as the countdown ends matter for your payoff. For instance, GREEN's payoff depends only on his **last** number posted, and on THE MINIMUM NUMBER POSTED by his group members **at the end of the countdown**.

The following probability facts and calculations may be useful:

1. Each player is expected to receive $.8 \times \frac{1}{6} \times 60 =$ **8 revision** opportunities during the 1-minute countdown.
2. The chance of a player receiving **no revision** opportunity during the 1-minute countdown is approximately $(1 - .8 \times \frac{1}{6})^{60} \approx 0.000$, which is **approximately 0.**
3. For any **10 second interval**, the chance of receiving at least one revision opportunity is of **approximately 75%.**
4. For any **20 second interval**, the chance of receiving at least one revision opportunity is of **approximately 95%.**

L Instructions: Standard Cheap Talk

Instructions

This is an experiment in decision making. Funds have been provided to run this experiment. If you follow instructions and make good decisions you may earn a substantial amount of money, that will be paid to you in CASH at the end of the experiment. What you earn depends partly on your decisions and partly on the decisions of others.

The entire session will take place through computer terminals, and all interactions between you will be done through the computers. Please, do not talk or communicate in any way during the session. Please, turn off your phones now.

You will be randomly divided in groups of **6** persons, and will make a sequence of **10** decisions as a part of that group. After 10 periods, all groups will be disband and the phase will end. This will be the end of the experiment.

Task Description

Each period, you and every member of your group will choose an integer: **1, 2, 3, 4, 5, 6 or 7**. Your choice and the smallest number chosen in your group (**including yours**) will determine your payoff in that period. Table 1 presents your payoffs in all possible scenarios. For example, if you choose number 5 and the smallest number chosen in your group is 4 you will get 78 Cents ($.78).

		Smallest Number Chosen						
		7	6	5	4	3	2	1
Your Choice	7	1.30	1.10	0.90	0.70	0.50	0.30	0.10
	6	—	1.14	0.94	0.74	0.54	0.34	0.14
	5	—	—	0.98	0.78	0.58	0.38	0.18
	4	—	—	—	0.82	0.62	0.42	0.22
	3	—	—	—	—	0.66	0.46	0.26
	2	—	—	—	—	—	0.50	0.30
	1	—	—	—	—	—	—	0.34

Table 1 – Payoff from different actions

1-minute Countdown

Graph Description

Before the 1-minute countdown, you and every member of your group have to choose a number to be posted on the graph: **1, 2, 3, 4, 5, 6 or 7**. Once every member of your group have made their initial choice of their **graph-number**, the 1-minute countdown begins.

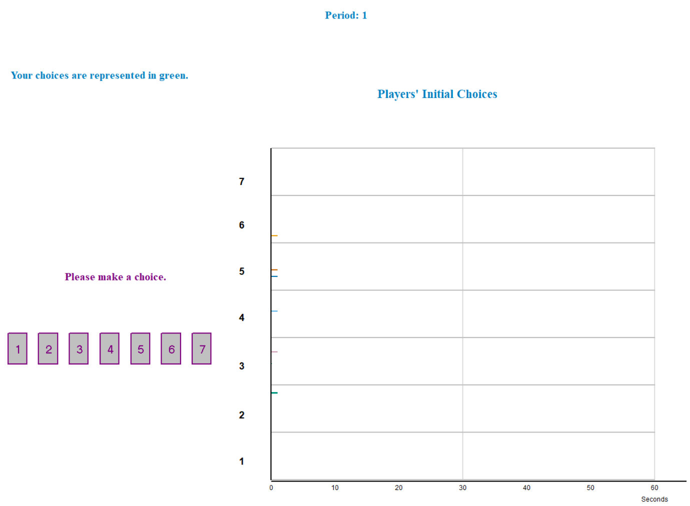


Figure 1 – Screen-shot of one possible scenario, as soon as the 1-minute countdown begins.

When the 1-minute countdown begins your screen will appear as in Figure 1. In Figure 1, we have placed time in seconds on the horizontal axes and the initial number chosen by each of your group members on the vertical axes.

The graph-numbers chosen by you and your cohort are placed along the vertical line above the zero second mark. You will see the graph-number of every participant in your group. For instance, in Figure 1, we see that 2 players have chosen number 5, 1 player has 2, 1 player's graph number is 3, 1 player's number is 4, and 1 player's number is 6. Your graph-number is always represented in the graph with the color green, and those of others by other colors.

Choice

After the graph appears on your screen, you will have to choose a number. **This number combined with the smallest number chosen in your group will determine you payoff in the period.** During the 1 minute, you will be able to change your chosen number at any time by placing your cursor on your desired number to the left of the screen. When you choose a number, it will light up as the number 2 now is. Your chosen number will **not** be displayed in the graph.

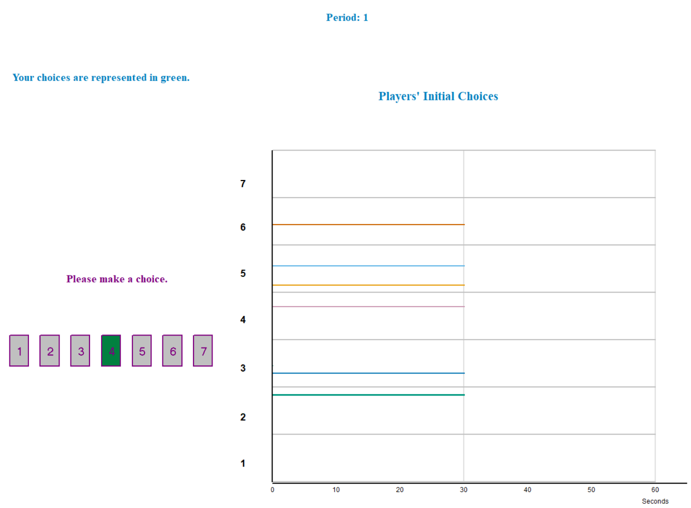


Figure 2 – Screen-shot of one possible scenario, after 30 seconds have passed.

When 30 seconds have passed your screen will appear as in Figure 2. You can still see the graph-numbers chosen by all players. Also, you can see on the left side of the screen that player GREEN is currently choosing the number 4 (it is lit up in green).

Note that only the number lit up in green at the end of 1-minute countdown is relevant for your payoff; numbers chosen during the 1-minute countdown or the graph-number DO NOT affect your payoff.

Final Payoffs

At the end of the 1 minute countdown, you will receive a payoff that depends on the number you have chosen (the number lit in green at the end of the countdown) and on the smallest number chosen by a player in your group. *Only the numbers selected at the* **end** *of the countdown matter for your payoff.* The numbers selected before do not matter at all for your payoff.

Your **final payoff** will be the sum of payoffs from all 10 periods plus the show up fee.

M Instructions: Revision Cheap Talk

Instructions

This is an experiment in decision making. Funds have been provided to run this experiment. If you follow instructions and make good decisions you may earn a substantial amount of money, that will be paid to you in CASH VOUCHERS at the end of the experiment. What you earn depends partly on your decisions and partly on the decisions of others.

The entire session will take place through computer terminals, and all interactions between you will be done through the computers. Please, do not talk or communicate in any way during the session. Please, turn off your phones now.

You will be randomly divided in groups of **6** persons, and will make a sequence of **10** decisions as a part of that group. After 10 periods, all groups will be disband and the phase will end. This will be the end of the experiment.

Task Description

Each period, you and every member of your group will choose an integer: **1, 2, 3, 4, 5, 6 or 7**. Your choice and the smallest number chosen in your group (**including yours**) will determine your payoff in that period. Table 1 presents your payoffs in all possible scenarios. For example, if you choose number 5 and the smallest number chosen in your group is 4 you will get 78 Cents ($.78).

		Smallest Number Chosen						
		7	6	5	4	3	2	1
Your Choice	7	1.30	1.10	0.90	0.70	0.50	0.30	0.10
	6	—	1.14	0.94	0.74	0.54	0.34	0.14
	5	—	—	0.98	0.78	0.58	0.38	0.18
	4	—	—	—	0.82	0.62	0.42	0.22
	3	—	—	—	—	0.66	0.46	0.26
	2	—	—	—	—	—	0.50	0.30
	1	—	—	—	—	—	—	0.34

Table 1 – Payoff from different actions

Once you and all the members of your group have chosen a number, a 1-minute countdown will begin.

1-minute Countdown

1. *Graph Description*

   Before the 1-minute countdown, you and every member of your group have chosen a number: **1, 2, 3, 4, 5, 6 or 7**. Once every member of your group has made their initial choice, the 1-minute countdown begins.

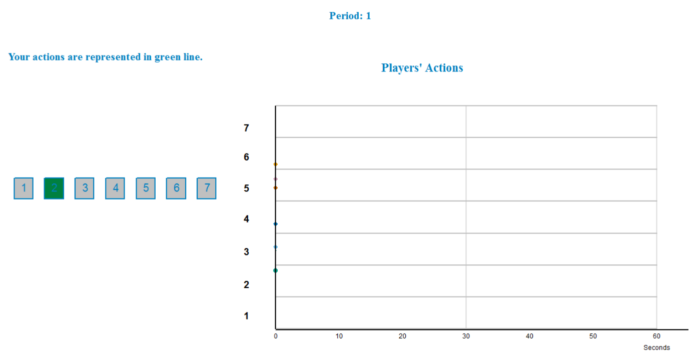
   

   Figure 1 – Screen-shot of one possible scenario, as soon as the 1-minute countdown begins.

   When the 1-minute countdown begins your screen will appear as in Figure 1. In Figure 1, we have placed time in seconds on the horizontal axes and the number chosen by each of your group members on the vertical axes.

   The initially picked numbers chosen by you and your cohort are place along the vertical line above the zero second mark. You will see the number posted of every participant in your group. For instance, in Figure 1, we see that 2 players have chosen number 5, 1 player has chosen 2, 1 player has chosen 3, 1 player has chosen 4 and 1 player has chosen 6. Your choice is always represented in the graph with the color green, and those of others by other colors. As you can see the player has CHOSEN NUMBER 2.

   As time continues, during the 1 minute, you will be able to change your chosen number at any time by placing your cursor on your desired number to the left of the screen. When you choose a number, it will light up as the number 2 now is.

2. *Revision Opportunities*

   However, the fact that you have changed your choice DOES NOT imply that the number on the graph will change. The number on the graph will only change if a **revision opportunity** is awarded to you. A revision opportunity is awarded at random times.

   Every second a revision opportunity will be awarded to the group with 80% chance. When a revision opportunity is awarded to the group, it will be given to one of the 6 group members, with equal probability of $\frac{1}{6}$. So the chance of any other member of your group having a revision opportunity and being able to change the posted number is exactly equal to yours: $p = .8 \times \frac{1}{6} \approx 13\%$.

If you had changed the number chosen, and received a revision opportunity, your number on the graph will change (the GREEN line will shift). If a revision opportunity is awarded to you, but you had not previously changed your chosen number, the number on the graph will **not** change. Let's call the number that you have chosen (the one that is lit up) which appears on the graph, your NUMBER POSTED on the graph.

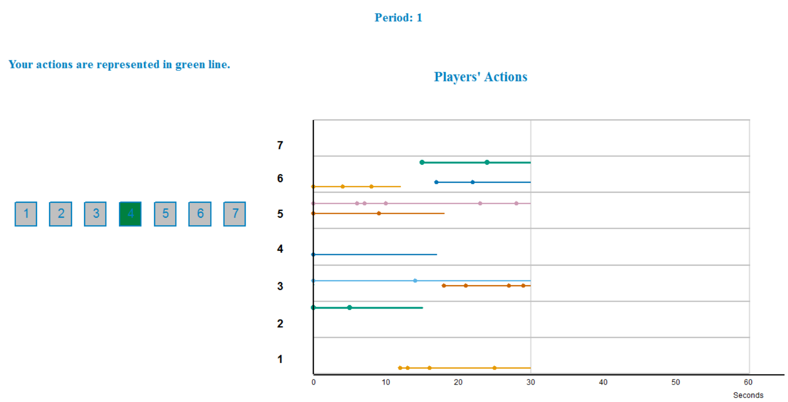


Figure 2 – Screen-shot of one possible scenario, after 1 minute has passed.

When 30 seconds have passed your screen will appear as in Figure 2. You can see how many times any member of your group changed the number posted (the line changes) as well as whether a revision opportunity was awarded (*a dot on the line*). For instance, player PURPLE has not changed the number posted (which is 5) despite having received 5 revision opportunities (5 dot's on light purple line). On the other hand, player ORANGE initially chose number 5, but after about 20 seconds the posted number became 3. Player GREEN has changed the number posted once. Let's take a closer look at player GREEN's actions:

(a) GREEN initially chose to post 2.

(b) Then, in the 4th second, a revision opportunity arrived, but the number posted by player GREEN did not change.

(c) In second 15, a revision opportunity arrived and the number posted changed to 6. Note that this was only possible because he had changed the number chosen prior to the arrival of revision opportunity.

(d) In second 25, revision opportunity arrived, but the number posted didn't change.

Finally, note that player GREEN has chosen the number 4 (it is lit up in green), but given that no revision opportunity has arrived, the NUMBER POSTED on the graph is still 6.

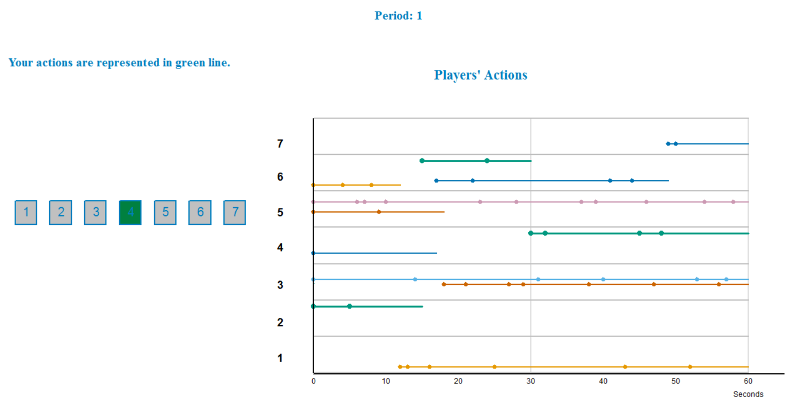
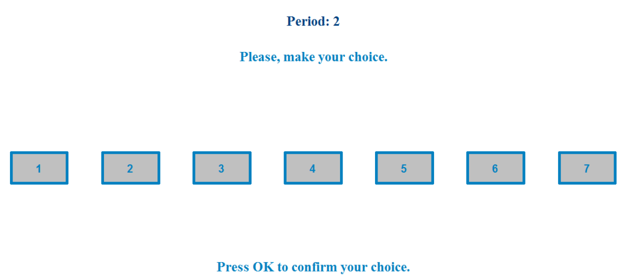


Figure 3 – Screen-shot of one possible scenario, after the 1-minute countdown has finished.

When 1-minute has passed your screen will appear as in Figure 3. You can see the number posted of every participant in your group.

3. *Final Choice*

   Once 1-minute countdown is over you will see a screen like the one bellow. You pick a number and **this number combined with the minimum number chosen in your group will determine you payoff in the period.** Note that only numbers chosen after 1-minute countdown are relevant for your payoff, numbers chosen during the 1-minute countdown *do not* affect your payoff.



4. *Final Payoffs*

   Your **final payoff** will be the sum of payoffs from all 10 periods plus the show up fee.

The following probability facts and calculations may be useful:

1. Each player is expected to receive $.8 \times \frac{1}{6} \times 60 =$ **8 revision** opportunities during the 1-minute countdown.
2. The chance of a player receiving **no revision** opportunity during the 1-minute countdown is approximately $(1 - .8 \times \frac{1}{6})^{60} \approx 0.000$, which is **approximately 0.**
3. For any **10 second interval**, the chance of receiving at least one revision opportunity is of **approximately 75%.**
4. For any **20 second interval**, the chance of receiving at least one revision opportunity is of **approximately 95%.**

N Instructions: Infrequent Revision Mechanism

Instructions

This is an experiment in decision making. Funds have been provided to run this experiment. If you follow instructions and make good decisions you may earn a substantial amount of money, that will be paid to you in CASH VOUCHERS at the end of the experiment. What you earn depends partly on your decisions and partly on the decisions of others.

The entire session will take place through computer terminals, and all interactions between you will be done through the computers. Please, do not talk or communicate in any way during the session. Please, turn off your phones now.

You will be randomly divided in groups of **6** persons, and will make a sequence of **10** decisions as a part of that group. After 10 periods, all groups will be disband and the phase will end. This will be the end of the experiment.

Task Description

Each period, you and every member of your group will choose an integer: **1, 2, 3, 4, 5, 6 or 7**. Your choice and the smallest number chosen in your group (**including yours**) will determine your payoff in that period. Table 1 presents your payoffs in all possible scenarios. For example, if you choose number 5 and the smallest number chosen in your group is 4 you will get 78 Cents ($.78).

		Smallest Number Chosen						
		7	6	5	4	3	2	1
Your Choice	7	1.30	1.10	0.90	0.70	0.50	0.30	0.10
	6	—	1.14	0.94	0.74	0.54	0.34	0.14
	5	—	—	0.98	0.78	0.58	0.38	0.18
	4	—	—	—	0.82	0.62	0.42	0.22
	3	—	—	—	—	0.66	0.46	0.26
	2	—	—	—	—	—	0.50	0.30
	1	—	—	—	—	—	—	0.34

Table 1 – Payoff from different actions

Once you and all the members of your group have chosen a number, a 1-minute countdown will begin. Only the number posted at the end of the countdown matters for your payoff.

1-minute Countdown

1. *Graph Description*

   Before the 1-minute countdown, you and every member of your group have chosen a number: **1, 2, 3, 4, 5, 6 or 7**. Once every member of your group has made their initial choice, the 1-minute countdown begins.

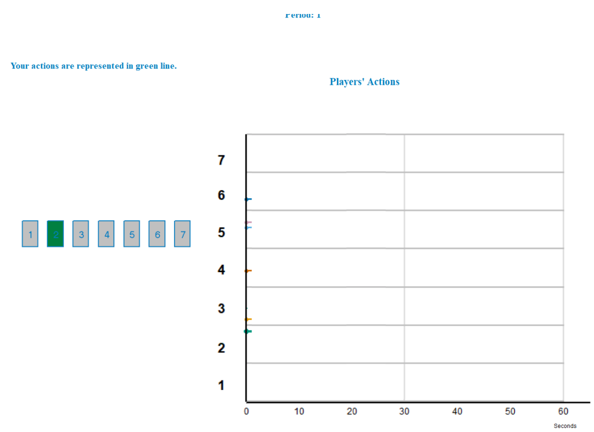
   

   Figure 1 – Screen-shot of one possible scenario, as soon as the 1-minute countdown begins.

   When the 1-minute countdown begins your screen will appear as in Figure 1. In Figure 1, we have placed time in seconds on the horizontal axes and the number chosen by each of your group members on the vertical axes.

   The initially picked numbers chosen by you and your cohort are place along the vertical line above the zero second mark. You will see the number posted of every participant in your group. For instance, in Figure 1, we see that 2 players have chosen number 5, 1 player has chosen 2, 1 player has chosen 3, 1 player has chosen 4 and 1 player has chosen 6. Your choice is always represented in the graph with the color green, and those of others by other colors. As you can see the player has CHOSEN NUMBER 2.

   As time continues, during the 1 minute, you will be able to change your chosen number at any time by placing your cursor on your desired number to the left of the screen. When you choose a number, it will light up as the number 2 now is.

2. *Revision Opportunities*

   However, the fact that you have changed your choice DOES NOT imply that the number on the graph will change. The number on the graph will only change if a **revision opportunity** is awarded to you. A revision opportunity is awarded at random times.

   Every second a revision opportunity will be awarded to the group with 10% chance. When a revision opportunity is awarded to the group, it will be given to one of the 6 group members, with equal probability of $\frac{1}{6}$. So the chance of any other member of your group having a revision opportunity and being able to change the posted number is exactly equal to yours: $p = .1 \times \frac{1}{6} \approx 1.6\%$.

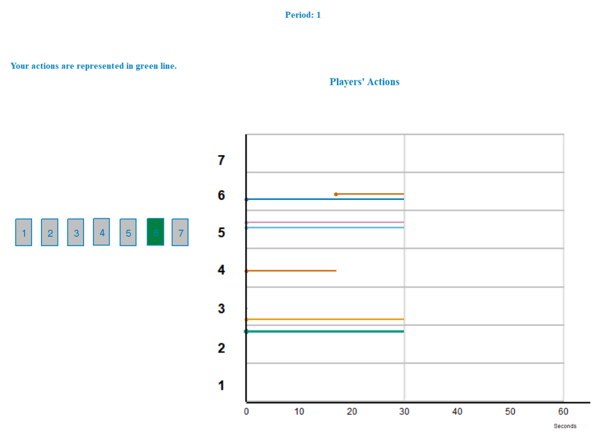


Figure 2 – Screen-shot of one possible scenario, after 30 seconds have passed.

If you had changed the number chosen, and received a revision opportunity, your number on the graph will change (the GREEN line will shift). If a revision opportunity is awarded to you, but you had not previously changed your chosen number, the number on the graph will **not** change. Let's call the number that you have chosen (the one that is lit up) which appears on the graph, your NUMBER POSTED on the graph.

When 30 seconds have passed your screen will appear as in Figure 2. You can see how many times any member of your group changed the number posted (the line changes) as well as whether a revision opportunity was awarded (*a dot on the line*). For instance, player ORANGE initially chose number 4, but after about 20 seconds the posted number became 6. Player GREEN has not changed the number posted. Note that player GREEN has chosen the number 6 (it is lit up in green), but given that no revision opportunity has arrived, the NUMBER POSTED on the graph is still 2.

3. *Final Payoffs*

At the end of the 1 minute countdown, you will receive a payoff that depends on your number posted and on the smallest number posted by a player in your group. *Only the numbers posted at the* **end** of the countdown matter for your payoff. The numbers posted before do not matter at all for your payoff. Your **final payoff** will be the sum of payoffs from all 10 periods plus the show up fee.

When 1-minute has passed your screen will appear as in Figure 3. You can see the number posted of every participant in your group. You will also see how many times has any member of your group changed the number posted (the line changes) as well as whether a revision opportunity was awarded (a dot in the middle of the line). For instance, players yellow and pink had no revision opportunity during the 1-minute countdown, players light and dark blue had 1 revision each, and players orange and green had three revisions each. In particular, player green the number posted 2 times. Let us take a closer look at player GREEN:

(a) She initially chose to post 2.

(b) In second 31, a revision opportunity arrived and the number posted changed to 6. Note that this was only possible because she had changed the number chosen prior to the arrival of revision opportunity.

(c) In seconds 37, another revision opportunity arrived and the number posted changed to 4.

(d) In second 55, a revision opportunity arrived, but the number posted didn't change.

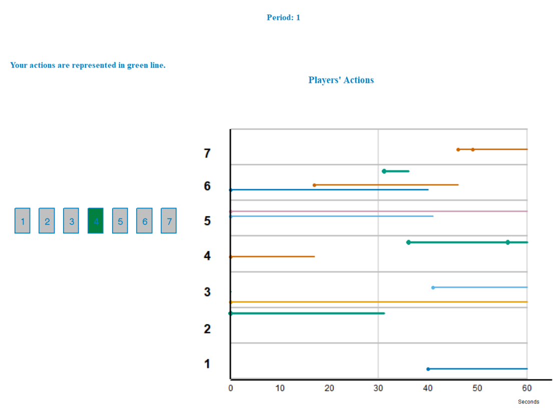


Figure 3 – Screen-shot of one possible scenario, after the 1-minute countdown has finished.

Note that only the number posted as the countdown ends matter for your payoff. For instance, GREEN's payoff depends only on his **last** number posted, and on THE MINIMUM NUMBER POSTED by his group members **at the end of the countdown**.

The following probability facts and calculations may be useful:

1. Each player is expected to receive $.1 \times \frac{1}{6} \times 60 = \mathbf{1}$ **revision** opportunities during the 1-minute countdown.

2. The chance of a player receiving **no revision** opportunity during the 1-minute countdown is approximately $(1 - .1 \times \frac{1}{6})^{60} \approx 0.36$, which is **approximately 36%.**

3. For any **10 second interval**, the chance of receiving at least one revision opportunity is of **approximately 15%.**

4. For any **20 second interval**, the chance of receiving at least one revision opportunity is of **approximately 30%.**

O Instructions: Random Revision Mechanism

Instructions

This is an experiment in decision making. Funds have been provided to run this experiment. If you follow instructions and make good decisions you may earn a substantial amount of money, that will be paid to you in CASH VOUCHERS at the end of the experiment. What you earn depends partly on your decisions and partly on the decisions of others.

The entire session will take place through computer terminals, and all interactions between you will be done through the computers. Please, do not talk or communicate in any way during the session. Please, turn off your phones now.

You will be randomly divided in groups of **6** persons, and will make a sequence of **10** decisions as a part of that group. After 10 periods, all groups will be disband and the phase will end. This will be the end of the experiment.

Task Description

Each period, you and every member of your group will choose an integer: **1, 2, 3, 4, 5, 6 or 7**. Your choice and the smallest number chosen in your group (**including yours**) will determine your payoff in that period. Table 1 presents your payoffs in all possible scenarios. For example, if you choose number 5 and the smallest number chosen in your group is 4 you will get 78 Cents ($.78).

		Smallest Number Chosen						
		7	6	5	4	3	2	1
	7	1.30	1.10	0.90	0.70	0.50	0.30	0.10
	6	—	1.14	0.94	0.74	0.54	0.34	0.14
	5	—	—	0.98	0.78	0.58	0.38	0.18
Your Choice	4	—	—	—	0.82	0.62	0.42	0.22
	3	—	—	—	—	0.66	0.46	0.26
	2	—	—	—	—	—	0.50	0.30
	1	—	—	—	—	—	—	0.34

Table 1 – Payoff from different actions

Once you and all the members of your group have chosen a number, a 1-minute countdown will begin. Only the number posted at the end of the countdown matters for your payoff.

1-minute Countdown

1. *Graph Description*

   Every round computer will randomly choose your initial number: **1, 2, 3, 4, 5, 6 or 7**. Once every member of your group has seen their initial choice, the 1-minute countdown begins.

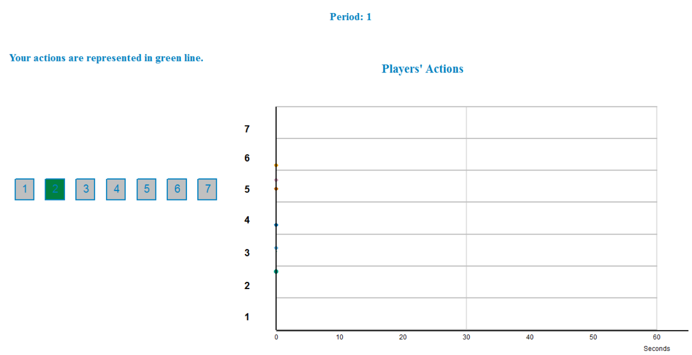


Figure 1 – Screen-shot of one possible scenario, as soon as the 1-minute countdown begins.

   When the 1-minute countdown begins your screen will appear as in Figure 1. In Figure 1, we have placed time in seconds on the horizontal axes and the number chosen for each of your group members on the vertical axes.

   The initially picked numbers for you by the computer are place along the vertical line above the zero second mark. You will see the number posted of every participant in your group. For instance, in Figure 1, we see that 2 players' initial number is 5, 1 player's initial number is 2, 1 player's initial number is 3, 1 player's initial number is 4 and 1 player's initial number is 6. Your choice is always represented in the graph with the color green, and those of others by other colors. As you can see the player's initial number is 2.

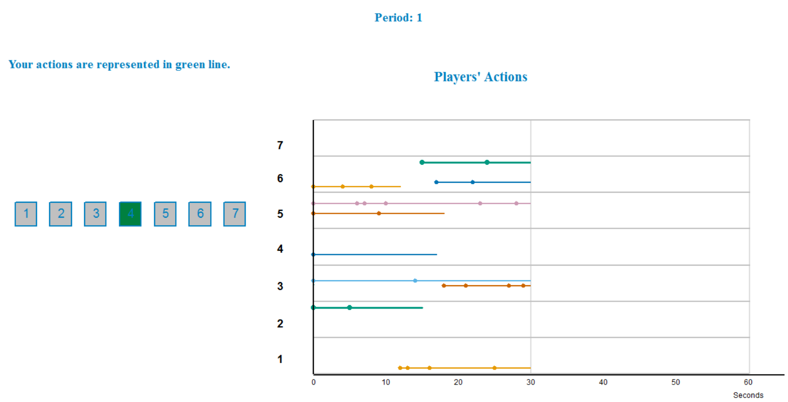
   As time continues, during the 1 minute, you will be able to change initial number chosen by the computer at any time by placing your cursor on your desired number to the left of the screen. When you choose a number, it will light up as the number 2 now is.

2. *Revision Opportunities*

   However, the fact that you have changed your choice DOES NOT imply that the number on the graph will change. The number on the graph will only change if a **revision opportunity** is awarded to you. A revision opportunity is awarded at random times.

   Every second a revision opportunity will be awarded to the group with 80% chance. When a revision opportunity is awarded to the group, it will be given to one of the 6 group members, with equal probability of $\frac{1}{6}$. So the chance of any other member of your group having a revision opportunity and being able to change the posted number is exactly equal to yours: $p = .8 \times \frac{1}{6} \approx 13\%$.

If you had changed the number chosen, and received a revision opportunity, your number on the graph will change (the GREEN line will shift). If a revision opportunity is awarded to you, but you had not previously changed your chosen number, the number on the graph will **not** change. Let's call the number that you have chosen (the one that is lit up) which appears on the graph, your NUMBER POSTED on the graph.



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(a) GREEN's initially chosen number by the computer was 2.

(b) Then, in the 4th second, a revision opportunity arrived, but the number posted by player GREEN did not change.

(c) In second 15, a revision opportunity arrived and the number posted changed to 6. Note that this was only possible because he had changed the number chosen prior to the arrival of revision opportunity.

(d) In second 25, revision opportunity arrived, but the number posted didn't change.

Finally, note that player GREEN has chosen the number 4 (it is lit up in green), but given that no revision opportunity has arrived, the NUMBER POSTED on the graph is still 6.

3. *Final Payoffs*

   At the end of the 1 minute countdown, you will receive a payoff that depends on your number posted and on the smallest number posted by a player in your group. *Only the numbers posted at the* **end** of the countdown matter for your payoff. The numbers posted before do not matter at all for your payoff. Your **final payoff** will be the sum of payoffs from all 10 periods plus the show up fee.

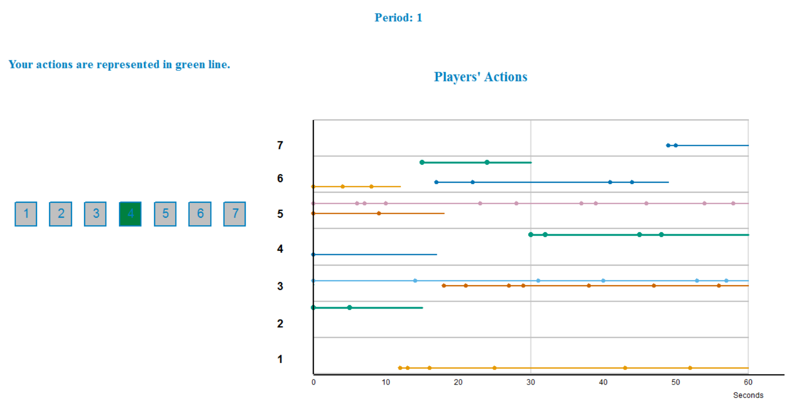

Figure 3 – Screen-shot of one possible scenario, after the 1-minute countdown has finished.

When 1-minutes have passed your screen will appear as in Figure 3. You can see the number posted of every participant in your group. Note that only the number posted as the countdown ends matter for your payoff. For instance, GREEN's payoff depends only on his **last** number posted, and on THE MINIMUM NUMBER POSTED by his group members **at the end of the countdown**.

The following probability facts and calculations may be useful:

1. Each player is expected to receive $.8 \times \frac{1}{6} \times 60 =$ **8 revision** opportunities during the 1-minute countdown.

2. The chance of a player receiving **no revision** opportunity during the 1-minute countdown is approximately $(1 - .8 \times \frac{1}{6})^{60} \approx 0.000$, which is **approximately 0.**

3. For any **10 second interval**, the chance of receiving at least one revision opportunity is of **approximately 75%.**

4. For any **20 second interval**, the chance of receiving at least one revision opportunity is of **approximately 95%.**