A Road to Efficiency Through Communication and Commitment*

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Abstract

We examine the efficiency gains of introducing a pre-play phase—allowing agents to communicate their intentions and commit to them—in a game with Pareto ranked equilibria. We focus on a game in which a Pareto inferior equilibrium is usually chosen. We first derive the theoretical conditions under which the efficient equilibrium is unique in the extended game and then we test our theory in the lab. The introduction of the pre-play revision phase increases the coordination on the Pareto dominant equilibrium, restoring over 50% of the efficiency lost in the standard setting. The results shed new light on cheap talk and reveal that a combination of communication and commitment leads to significantly higher welfare.

JEL Classification: C73, C92, P41; **Keywords:** Coordination Games, 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. For instance, firms have to make investment decisions, and their returns depend on the amount invested by other firms; thus, coordination failure may limit economic activity with firms choosing suboptimal investment levels (see, for instance, Rosenstein-Rodan (1943)). A common feature of coordination games is the existence of multiple Pareto ranked equilibria. Thus, coordination failure traps all involved in unsatisfactory situations, as outcomes preferred by all are not only possible, but would also be stable if ever reached.

Although the benefits of overcoming coordination failures are obvious, it is not clear how institutions help agents overcome coordination failure. Recent experimental research has focus on how different institutions lead to coordination on a better equilibrium, and a key point has been the introduction of communication among players. On the one hand, some experimental evidence suggests that communication may improve efficiency by increasing coordination on the optimal action profile. On the other hand, there are cases in which communication has no significant effect.[1] However, given that the introduction of communication does not always impact the set of equilibria, it is not clear how or why it would help players coordinate on the Pareto efficient equilibrium.

In this paper, we investigate a particular protocol—an asynchronous revision pre-play phase—and focus on how it can reduce coordination failure and allow those involved to reach higher payoffs. We rely on the theoretical work of Calcagno et al. (2014)[2] which proposes a communication protocol, and shows theoretically that it selects the payoff-dominant equilibrium as *the unique equilibrium* of a coordination game. The protocol consists of an asynchronous revision pre-play phase in which a player can change her chosen action at random times, and only the strategy chosen in the last instant is payoff-relevant. In contrast to focal point or cheap talk,[3] the introduction of a pre-play phase directly affects the

[1] There are some communication protocols, such as one-way communication or public announcements, that have been documented to increase coordination. However, other protocols, such as two-way communication or private advice, have led to coordination failures (see Cooper et al. (1992), Chaudhuri et al. (2009), Charness (2000), Blume and Ortmann (2007), Burton and Sefton (2004) and Feltovich and Grossman (2014)).

[2] See Kamada and Kandori (2009), where the authors first introduce and define revision games.

[3] Focal point is one particular equilibrium that players will tend to play, given that it seems natural, or special, to them (see Schelling (1960)), while cheap talk is the capacity of players to communicate in a non-binding

set of equilibria, and the Pareto dominant equilibrium of the coordination game becomes the unique equilibrium.

We experimentally investigate the efficacy of the introduction of an asynchronous revision pre-play communication protocol in improving payoffs in coordination games. We embed a revision mechanism into a minimum-effort game, in which players can observe the actions of all their group members in real time (we call the treatment without a pre-play phase *baseline*, and with a pre-play phase *revision mechanism*). The pre-play phase starts with all group members choosing an initial action, which, if an opportunity arises, they can revise during a preparation period of sixty seconds. Revision opportunities are awarded randomly to each group member according to independent probability distributions (probability of two group members receiving a revision opportunity in the same instant is zero–hence, revisions are asynchronous). In one graph changing over time, each player can see real-time information on all group members' revision opportunities, posted action and the history of posted actions and revisions. At the end of the pre-play phase, the actions most recently revised are played out; thus, as the deadline approaches, players become more committed to their choices. In standard cheap talk protocols, sent messages have no binding effect on taken actions, while in the revision mechanism setup, the message may become the final choice with some strictly positive probability. Consequently, messages in the pre-play phase may directly impact final choices and thus, payoffs.

We show that, as the theory predicts, the introduction of the revision mechanism increases coordination on the Pareto best equilibrium. Actions chosen in the treatment with the pre-play phase are significantly higher than in the treatment without the pre-play phase. Furthermore, our results suggest that miscoordination in the revision mechanism treatment is essentially nonexistent, as variation in the chosen action decreases over periods and is virtually absent towards the end. As for efficiency, we calculate the loss by comparing average payoffs earned by our subjects in both treatments, compared to the maximum payoff. In every period, subjects earn significantly more in the treatment with the pre-play phase than without it. Moreover, the revision opportunity treatment is able to restore more than half of the welfare lost in the baseline.

The introduction of an asynchronous revision pre-play phase to the game increases the coordination on the efficient equilibrium profile. To further understand why this protocol

way (see Farrell (1995), Farrell and Rabin (1996) and Crawford (1998)).

improves coordination, we examine the forces behind our main treatment. The revision mechanism combines two components: *(i) communication* and *(ii) commitment.* During the pre-play phase, players publicly *communicate* their intended actions, and can change them when a revision opportunity occurs. The action chosen at the end of the countdown is the action played. Thus, as the deadline approaches, players effectively *commit* to their chosen action. To separate the importance of both components, we run an additional treatment, cheap talk, in which the pre-play revision mechanism is non-binding. Such treatment is identical to the revision mechanism, except that the action chosen at the end of the countdown is payoff-irrelevant. When the countdown ends, agents are asked to choose a strategy to be played and are paid based only on that choice. Our results reveal the importance of both communication and commitment for better coordination, as the payoffs are significantly higher in the revision mechanism than in the cheap talk treatment.

The experimental procedure in this paper allows us to study not only the final outcomes of players' interactions, but also the process and strategies leading to them. We collect data on how players revise their strategies during the countdown to analyze how players use revision opportunities to communicate and to coordinate with other players. We investigate whether the strategies used during the countdown are compatible with the theory in Calcagno et al. (2014). The main intuition behind the theoretical result is that, in an instant far removed from the deadline, if at least one subject is not choosing the highest effort, then: (i) if a player choosing the highest effort had a revision opportunity, she would not revise her action; and (ii) if a player choosing a lower effort (even if not the minimum) had a revision opportunity, she would revise her action upwards. Although (ii) seems counter-intuitive, as it would lower the agent's payoff if no other revision were to follow, Calcagno et al. (2014) show that it is optimal to increase one's effort choice as it induces others to also raise their effort choices.

Aligned with the theoretical intuition, we present two results. First, we show that when a subject is choosing a higher effort the probability of revising her action is only 8.4% and it is four times smaller than when a subject is choosing a lower effort. Second, we take a closer look at the revised actions chosen by the subjects, and test for the presence of forward induction (Kohlberg and Mertens (1986)).[4] We find that almost half of the initial revisions and a quarter of all revisions are forward thinking—players revise their strategies in a way that

[4] See Cachon and Camerer (1996) for experimental evidence on forward induction, and for more recent work Evdokimov and Rustichini (2016) and Balkenborg and Nagel (2016).

would lower their payoffs if no other revision occurred subsequently. The difference between the initial and overall revisions suggests that the communication embedded in the forward thinking revisions plays a more important role at the beginning of the players' interaction, when there is more strategic uncertainty and the deadline is farther in the future.

The revision mechanism presented and tested in this paper can be interpreted in two distinct ways. First, it can be understood as a dynamic coordination game in which agents have to prepare their actions and cannot change these preparations instantaneously. Second, one can interpret this extended game—including the revision opportunities—as a mechanism to implement the efficient outcome.

Following the first interpretation, the revision mechanism could be a more realistic depiction of real-world coordination settings: before taking an action, players have to prepare it. For instance, consider firms investing in a joint project. It is natural to think that the investment is more profitable for a firm when the other firm's investments are higher. Also, even though there is a deadline for the investments to be made, firms communicate and plan their investments for a long time. While firms make preparations, they often cannot change them in an instant or, sometimes, cannot alter them at all due to administrative procedures and obligations to other projects, among other reasons. Thus, adjustments can be made only if an opportunity arises.

A distinct interpretation for the pre-play phase is the mechanism design approach: the revision mechanism is not already in place; rather, a central planner can introduce such a mechanism to improve efficiency. Our result on the significant increase of coordination in the Pareto efficient equilibrium suggests a policy that might be implemented to reduce inefficiency in coordination settings. The inability to coordinate investments could significantly constrain economic development (see, for example, Murphy et al. (1988)), and implementing the revision mechanism could increase the coordination on a higher investment equilibrium, thus raising welfare. Our paper shows that implementing the revision mechanism leads to higher efficiency than simply letting players communicate before taking an action.

The rest of the paper is organized as follows. Section 2 presents an overview of the literature. In Section 3, we introduce the model and the main theoretical result: the uniqueness of the Pareto dominant equilibrium in the game that includes a pre-play phase. Section 4 states our implementation of the theory — the experimental design. In Section 5, we report our results, and discuss how players coordinate their actions, as well as the importance of

revisions for coordination. Section 6 concludes the paper.

2 Literature Review

Consider the following minimum-effort game: a group of workers have to simultaneously decide how much effort to exert on a joint project. Each worker's payoff depends negatively on her effort choice and positively on the minimum effort exerted by her group members. The rate of return on the group's minimum effort more than compensates for individual investment costs. However, since exerting effort is costly, a player would never like to invest more than the minimum effort chosen by the group members.[5] Therefore, as long as all the group members choose the same effort, no player has any incentives to change her effort choice. The minimum-effort game exhibits multiplicity of equilibria, as there are as many equilibria as there are possible effort choices. Furthermore, all equilibria can be Pareto ranked, with a higher effort one dominating any equilibrium with lower effort.

Van Huyck et al. (1990) were the first to study the minimum-effort game in an experimental setting,[6] in which subjects played the game multiple times and, after every round, were informed about the minimum effort chosen in their group. The choice of effort presented a clear pattern, declining as rounds progressed and converging to the minimum effort.[7]

The convergence to the Pareto-worst equilibrium led to a literature examining the result's robustness in different settings. Treatments range from introducing continuous choices of efforts to group bonding activities preceding the actual game.[8] More aligned with our work are treatments that focus on monitoring group members' choices or the communication of their actions to each other. Some treatments proposed in the literature have proven successful in facilitating a higher frequency of coordination on the Pareto dominant equilibrium. In this paper, we provide a theory-based treatment, highlighting the importance of communication and commitment in fostering cooperation towards the payoff-dominant equilibrium.

[5] We are considering a one shot game and thus, choosing anything but the minimum effort chosen by the group as a signaling or teaching others can not be a valid motivation.

[6] They consider a game in which players choose an effort in the set $E = \{1, 2, 3, 4, 5, 6, 7\}$, and with payoff function $\pi_i(e) = 0.6 - 0.1e_i + 0.2 \min_j\{e_j\}$. Such a stage game was repeated ten times.

[7] This suggests a pattern of risk-dominance selection. For instance, see Carlsson and Van Damme (1993) and Cabrales et al. (2007) for theoretical and experimental evidence.

[8] See Goeree and Holt (2005), Chen and Chen (2011), Bornstein et al. (2002), Weber (2006), and Berninghaus and Ehrhart (1998) for how different treatments—from gradually growing group sizes to inter-group competition—affect coordination.

The impact of different monitoring structures on equilibria selection in coordination games has been a matter of contention in the literature. Van Huyck et al. (1990) and Devetag (2005) find that better ex-post monitoring devices fail to facilitate coordination on the payoff-dominant equilibrium, while Berninghaus and Ehrhart (2001) and Brandts and Cooper (2006) find a positive relationship between ex-post monitoring and coordination on the payoff dominant action profile. In our paper, we introduce an asynchronous revision pre-play communication phase and show, both theoretically and experimentally, its positive effect on coordination. A similar extension that has been studied in a minimum-game experimental setting is the introduction of a pre-play communication device. Such communication can be *costly* or *costless* or take the form of *intergenerational advice*.

Van Huyck et al. (1993) and Devetag (2005) consider a *costly* form of pre-play communication (a pre-play auction each round) and conclude that such an extension enables the players to achieve coordination on the payoff dominant profile. This experimental result is theoretically explained by Crawford and Broseta (1998).

More aligned with our work, Blume and Ortmann (2007) examine the introduction of simultaneous *costless* pre-play communication. Prior to each stage game, players sent a message (a number between 1 and 7) indicating how much effort they intended to exert. After observing the messages from all the group members, players had to choose the payoff-relevant effort level. In contrast with our main treatment, the messages were cheap talk - not binding in any way. The main result of the paper is that the pre-play cheap talk communication increases coordination on the dominant equilibrium. Note that, since messages are non-binding, there is no theoretical argument for why cheap talk communication should impact the set of equilibria. In comparison, the revision mechanism treatment of our paper introduces messages that become payoff-relevant actions, and this commitment directly impacts the set of equilibria. Moreover, introducing the revision mechanism reduces the set of equilibria to a singleton containing only the Pareto efficient action profile. This paper sheds new light on the result in Blume and Ortmann (2007), since we can test the difference between the revision mechanism with and without commitment. Our results suggest that both communication and commitment are important in promoting coordination on Pareto best equilibrium.

Finally, Chaudhuri et al. (2009) introduce *intergenerational advice* as a coordination device. The game is played by non-overlapping generations of players, who can pass on advice

to their successors in the game. The paper analyzes different levels of common knowledge of the advice, and "high quality" public announcements are shown to induce greater levels of coordination on payoff-dominant equilibrium. However, if advice is not sufficiently strong, the coordination is very sensitive to the manner of announcement distribution.

The paper by Deck and Nikiforakis (2012) is the first to study interim real-time monitoring in a minimum-effort game.[9] Players have exactly one minute to choose an action, and—in contrast to our paper—can switch the chosen action at any time. Depending on the monitoring structure, a player's movements might be observed by all players or by only a subset of them. The effort choice at the end of the period is used to determine payoffs. The authors examine various interim monitoring structures, and although there is no difference in the equilibrium set implied by each one of them, they conclude that—only if all players observe everybody's action choices—perfect monitoring increases the coordination on the payoff-dominant equilibrium. Similarly, in Leng et al. (2016), where subjects play a minimum-effort game in continuous time with the payoffs determined at each instant, perfect monitoring also increases coordination.

The results of our paper suggest that there is more to be done to increase coordination on payoff-dominant equilibrium. By comparing the cheap talk and the revision mechanism treatments, we show that not only communication, but also commitment, plays a crucial role in increasing efficiency.

3 The Model

Consider the following normal-form game $(I, (E_i)_{i\in I}, (\pi_i)_{i\in I}))$ in continuous time $-t \in [-T, 0]$, where I is a set of players, E_i a set of effort levels and $\pi_i(e) = \gamma + \alpha \cdot \min_{j\in I} e_j - \beta \cdot e_i$ is a payoff function for player i, with $\alpha > \beta > 0$. The normal-form game is played once and for all at time $t = 0$. At $-T$, players simultaneously choose an initial action and post it. Between $-T$ and 0, players independently obtain revision opportunities, according to a

[9] Building on Schelling (1960)'s insights, Dorsey (1992) was the first to introduce real-time monitoring and revisions in a voluntary contributions game. Similarly, Kurzban et al. (2001) allow real-time incremental contributions in the voluntary contribution mechanism (VCM) and find that this increases terminal contribution rates. Further, Goren et al. (2003) show that real-time contributions with irrevocable commitments aid overall contributions by reducing free riding. On the other hand, Duffy et al. (2007) test theoretical predictions of dynamic voluntary contribution game in Marx and Matthews (2000) and show that while dynamic setting increases the rate of contributions compared to the static case, the results don't seem to be driven by the theoretical insights.

Poisson process with arrival rate $\lambda_i > 0$, at which point they can change their previously chosen action. At $t = 0$, the posted action is taken, and each player receives the payoff that corresponds to it.

Note that a one-shot component of the game described above—i.e., the minimum-effort game—has *multiple equilibria*. As long as all players play the same pure strategy, it is a Nash equilibrium. However, under certain conditions, all of the dynamic revision minimum-effort game equilibria result in the same payoff and last instant actions of the *Pareto efficient equilibrium* of the one-shot game.

A public history is a sequence of posted actions and the history of revision opportunities for each group member, $\mathcal{H}_t = \left\{\{e_\tau\}_{\tau\in[-T,t)}, \{r_\tau\}_{\tau\in[-T,t)}\right\}$, where $e_\tau = (e_\tau^1, ..., e_\tau^{|I|})$, $e_\tau^i \in E_i$ and $r_\tau = (r_\tau^1, ..., r_\tau^{|I|})$, $r_\tau^i \in \{0, 1\}$. Let $\mathcal{H} := \cup_{t\in[-T,0]}\mathcal{H}_t$ be the set of all possible public histories. A history for player i at time t is $h_i(t) = \{(e_\tau, r_\tau)\}_{\tau\in[-T,t)} \in \mathcal{H}_t$. A strategy for player i is a mapping $\sigma_i : \mathcal{H} \to \Delta(E_i)$.

We apply Theorem A.2 from Calcagno et al. (2014) to a minimum-effort game vide supra and summarize the statement in the following Proposition.

Proposition 1 *In an Asynchronous Revision Minimum-Effort Game, if*

1. $\alpha > (n-1)\beta$ *(the return on group effort is sufficiently higher than the cost), and*
2. $r_i = 1/n, \forall i \in I$ *(revision opportunities are equally distributed amongst all players),*

then there exists $T' > 0$ *such that for all* $T > T'$*, the unique revision equilibrium (SPE) has* $e_0 = \max E_i$ *with probability* 1.

The proof of Proposition 1 uses Theorem A.2 from Calcagno et al. (2014) and it is in Appendix A. We will discuss the main idea of the original proof as it is very intuitive and it appeals to some relevant ideas discussed in this paper. First, note that if all players choose the maximum effort in a given instant, there is no reason for any player to ever deviate from it. Thus, one equilibrium of the dynamic game is all players choosing the maximum effort from the beginning. Let us now provide intuition for why it is the unique one. Assume that, in a given instant far removed from the deadline, all players but one choose the maximum effort (only one player chooses a different effort). That particular player has the incentive to change her effort choice to the maximum effort since, if she does so, her payoff will increase

to the maximum possible payoff. If there is enough time before the deadline and revision opportunities are quite common, it is beneficial for the other players to continue choosing the maximal effort, waiting for that particular player to have a revision opportunity. Now, assume that, in a given instant, all players but two choose the maximum effort. If one of the players that does not choose the maximum effort receives a revision opportunity, she should revise her effort to the maximum effort since she will induce the other player to follow in her footsteps, as described above. That is, she will revise her action because she knows that this will lead the other player to revise his. If revision opportunities are frequent enough for all players, the argument above unravels all other equilibrium candidates, as one player changing her effort choice begins a chain of events that leads all players to choose the highest effort level. In our experiment we find that almost half of the initial revisions resemble the idea described above, that is, half of all initial revisions follow the forward thinking reasoning which is at the core of the proof.

We proceed by describing how we design an experiment to closely replicate the conditions of our setup and to test the power of the pre-play revision mechanism in aiding coordination. First, we need to acknowledge the key challenges and our proposed resolutions. The game is set in continuous time, and players need to have perfect information in continuous time.[10] Every players' revision opportunity and posted action, as well as the history of posted actions 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. The players' actions are represented by different colors. Every time a player receives a revision opportunity, a dot shows up on that player's action line. This graph summarizes all the key information and makes it easily accessible to the subjects. A more detailed explanation of our graph and of the entire experiment is given in the next section.

[10] See Friedman and Oprea (2012) and Bigoni et al. (2015) for recents studies implementing 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.

4 Experimental Design[11]

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, on average, subjects earned $17 that included $8 dollar show up fee. The experiment consisted of three different treatments run with different subjects. In each session, written instructions were distributed to the subjects and also read aloud.

Participants were randomly divided in groups of six, and they made a sequence of ten decisions as a part of that group. Each group played the minimum-effort game with effort levels ranging from 1 to 7 and the payoff function: $\pi_i(e) = .18 - .04 \cdot e_i + .2 \cdot \min_{j \in I} e_j$.[12] The payoffs were described to subjects in matrix form, and the subjects then took a short comprehension test to ensure that they understood the payoff structure. After ten periods, subjects took a short survey and were paid their final payoff, which was the sum of the payoffs from all ten periods and the show-up fee (survey results are summarized in Appendix H).

In each of the three treatments, the instructions and the information available to the players were different. Let us describe the rules of each treatment one at a time.

4.1 Treatment 1: Baseline

After each period of playing a standard one-shot, minimum-effort game, participants received a feedback on the minimum number chosen in their group in that period. This 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

Every member of the group chose an integer from 1 to 7. Once all the group members had made their choices, the graph appeared, as in Figure 1[13] and a one-minute countdown began. In Figure 1, the time in seconds is on the horizontal axis and the number chosen by each

[11] Instructions used in our experiment can be found in the online Appendix.

[12] This payoff function is consistent with conditions in Proposition 1.

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

of the group members is the vertical axis. The initially picked numbers are placed along the vertical line above the zero second mark. Each player is represented in the graph with a different color.

As the countdown progressed, every member of the group could change the number chosen at any time by placing the cursor on the desired number on the left side of the screen. When a subject had selected a number, the respective button would turn green, as the number 4 is in Figure 1. The number posted on the graph would only get updated if a revision opportunity was awarded to a player and, who selected a number different from her previous choice.

Revision Opportunities: Every second, the group had an 80% chance of receiving a revision opportunity. When a revision opportunity was awarded to the group the six group members had then equal probability of $1/6$ of receiving the revision. The chance of any member of the group having a revision opportunity at any second was, thus, equal to approximately 13%.[14] Only the numbers posted at the end of the countdown mattered for the payoff. The numbers initially picked and all the revisions were payoff irrelevant.

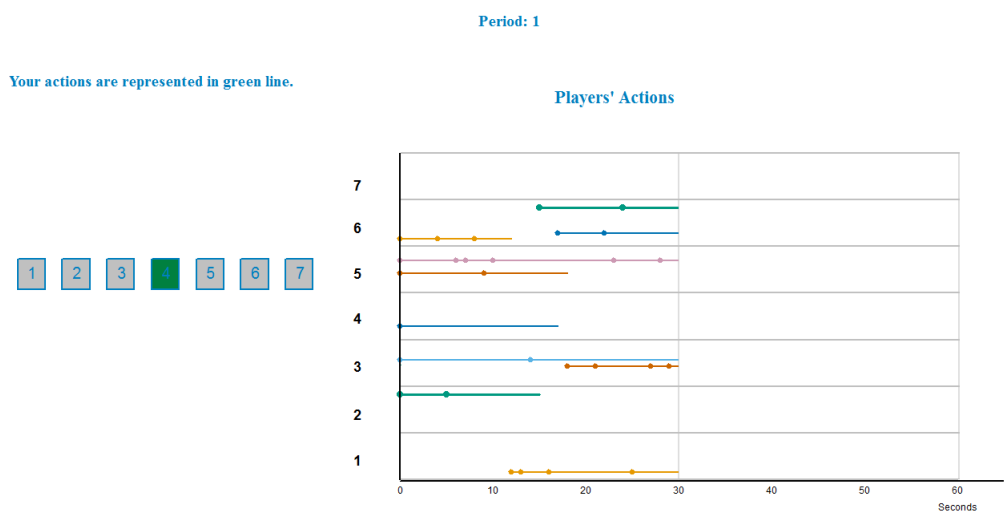


Figure 1: Sample Screen After 30 Seconds

Let us take a closer look at player Green's actions (thicker line on the graph), whose

[14] The theoretical result in Proposition 1 requires the revision opportunities to be frequent enough or the length of a period to be long enough (these two parameters are interchangeable). In Appendix D we test whether chosen T and λ in the experiment are robust and we conclude that our choice wasn't binding.

screen is shown in Figure 1. Along the vertical line above the zero-second mark, we see a green dot in the interval 2, which means that Green's initial choice was action 2. A dot on the green line (thicker line) at the five-second mark means that Green was awarded a revision opportunity as the action after that was not updated, Green did not change the intended action, still choosing 2. At 15-second mark, we see a shift of the green line from the action 2 interval to the action 6 interval. This implies that in the 15th second, the revision opportunity was awarded to Green, and prior to that, she had switched her action from 2 to 6. And at about 25-second mark, there is a green dot on the line, revealing that a revision opportunity was awarded but not used, as the green line is still in the same interval 6.

On the 30-second mark, one can observe each group member's current posted action. Players Green and Blue are at action 6; Purple is at 5; Light Blue and Orange are at 3 and Yellow is at 1. Thus, the current minimum action is 1. Note that on the left side of the graph in Figure 1, the number 4 is green. This implies that the player whose screen we are observing has switched her intended action from 6 to 4. However, the revision opportunity has not yet occurred; thus, the posted action on the graph is still action 6. At every second, we collect data on each player's intended action and posted action.

4.3 Treatment 3: Cheap Talk

The revision mechanism treatment combines two main forces to promote cooperation. First, it allows agents to communicate their intended actions to each other publicly. Second, it provides a partial commitment to the actions communicated. To separate these two forces, we run a cheap talk treatment.

Treatment 3 follows the Treatment 2 protocol, without commitment—i.e., the one-minute countdown is payoff-irrelevant. Following Treatment 2 protocol, all members of the group simultaneously choose an integer from 1 to 7. Once everyone makes their choice, the one-minute countdown begins. As in Treatment 2, all members of the group see the same real-time graph, and the action chosen is only updated when a revision opportunity is awarded. The distribution of revision probabilities is the same as in Treatment 2. In contrast to Treatment 2, the choice at the end of the countdown is not payoff relevant in Treatment 3. Once the 60-seconds countdown is up, a new screen appeared and subjects choose an integer from 1 to 7, as in the baseline treatment, and get paid accordingly. Only this last choice is payoff relevant.

Table 1 summarizes our experiment treatments and the number of sessions and subjects.

Table 1: Experimental Design

Treatment	**Sessions**[15]	**Task**	**No. of Subjects**
Treatment 1	1-2	Baseline	36
Treatment 2	3-5	Revision Mechanism (RM)	36
Treatment 3	6-8	Cheap Talk (CT)	36

5 Results

In this section, we present our experimental results and shed light on the effects of the introduction of the revision mechanism. We begin by analyzing our data using a simple table that shows the minimum effort choice by every group in the last period of both baseline and revision mechanism treatments. As we see from Table 2, two treatments result in very different outcomes: group minimum effort for five out of six groups is either 6 or 7 (the maximum possible effort level is 7) for the revision mechanism treatment, while no group in baseline treatment coordinated on an effort level higher than 5.

Table 2: Last Period Minimums in Descending Order

Revision Mechanism (RM)	7	7	7	6	6	1
Baseline Treatment (BT)	5	5	3	3	3	1

Table 2 suggests a significant difference between the equilibrium played in the revision mechanism and in the baseline treatment. We proceed by first documenting the statistical difference suggested in Table 2. Then, we analyze the dynamics of players' actions leading to that statistical significance. All of the tests reach similar conclusions: the introduction of the revision mechanism significantly increases the coordination on the payoff-dominant equilibrium, leading to higher payoffs.

First, we focus on the efficiency loss, comparing the revision mechanism and the baseline treatments. Deviations from the efficient equilibrium—all players choosing the Pareto

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

optimal equilibrium profile—reduce efficiency in two distinct ways: first, through miscoordination from the minimum effort, as some players do not respond optimally to other players' efforts; and second, through the inefficient minimum effort chosen, which affects all players' payoffs. The payoff function combines both forces and, thus, is a good measure of efficiency. Figure 2a presents the average payoff over periods for the two treatments. In every period, subjects earn more in the revision mechanism than in the baseline treatment and as periods proceed, we see the revision mechanism treatment leading to higher payoffs, while the average payoff in the baseline treatment stays essentially the same. The Figure 2a shows a clear divergence in average payoffs, but the difference between subjects' earnings in these two treatments is even stronger—the payoff distribution in the revision mechanism first-order stochastically dominates the distribution in the baseline treatment and a Kolmogorov-Smirnov (K-S) test of equal distributions is rejected at $p < 0.01$.

We calculate total earnings in both treatments and compare it to the highest possible payoff. Subjects' revision mechanism total payoff is 77.8% of the efficient payoff, while the baseline treatment is only 53.3%. Thus, the introduction of the revision mechanism is able to restore more than half (52.4%) of the efficiency lost in the baseline treatment.

The increase in payoffs in the main treatment is driven by two distinct effects: (i) the increase in coordination in a particular equilibrium; and (ii) the increase in coordination in the payoff-dominant equilibrium. To separate these two effects, we compare actions chosen in the baseline and the revision mechanism treatments, and we begin by analyzing the average minimum efforts, see Figure 2b.[16] The average minimum effort chosen in the revision mechanism is significantly higher than in the baseline treatment (the hypothesis of equal minimum effort distributions is rejected using a Mann-Whitney U (MWU) test, at the 1 percent level). Furthermore, note that minimum actions in the revision mechanism treatment are increasing over periods, as opposed to the steady average in the baseline treatment.

Next, we examine the frequency of the efficient action over the periods. Figure 2c summarizes our results. Both the revision mechanism and the baseline treatments start the first period at the same frequency of maximum effort (around 70%). However, the frequency with which the Pareto optimal equilibrium effort is chosen in the baseline treatment decreases rapidly over time, while the revision mechanism frequency stays virtually the same. The difference between the treatments increases over time, and in the last period, players in

[16] Group level data can be found in Appendix C and aggregate data by second is in Appendix B.

Figure 2: Baseline vs Revision Mechanism Treatment

the revision mechanism play the efficient action almost five times more often than players in the baseline treatment.

Finally, we test the null hypothesis of equal distributions of effort choices in both treatments in all periods combined and separately for each period. A Komogorov-Smirnov test rejects the hypothesis with $p < 0.01$ for all periods pooled together and also, for separate periods after Period 4.

Our central result is that the introduction of a pre-play phase, in which agents can revise their chosen actions—i.e., the revision mechanism—reduces the efficiency loss observed in the baseline treatment. This implies that agents have significantly higher payoffs in the revision mechanism than in the baseline treatment. An important part of the payoff difference can be attributed to the fact that agents play higher effort strategies in the former than in the latter. The introduction of the revision mechanism improves the coordination on a higher effort and also fosters a steady minimum action, unlike the rapid declining pattern observed

in the literature.

We now proceed to establish that the revision mechanism treatment provides more coordination on any particular equilibrium than the baseline treatment does. To examine this statement, we calculate the standard deviation of actions in every period for each group and average them over groups for both treatments. The results are displayed in Figure 2d. Higher standard deviations imply a higher degree of miscoordination among players of the same group, with players choosing very distinct actions. As we see in Figure 2d, the average standard deviation in the first few periods of both treatments is similar, and as periods progress, both standard deviations decline. However, notice that the standard deviation in the revision mechanism is always below that in the baseline treatment, and, in addition, in most of the later periods, four out of six groups' standard deviation is 0, as all the players in those groups were choosing exactly the same effort level. No group achieved such stability for more than a period in the baseline treatment.

5.1 What It Takes to Coordinate

To understand why the revision mechanism improves both the individual's ability to coordinate and the actual strategy profile on which players coordinate, we study the forces behind our main treatment. The revision mechanism combines two distinct forces: first, it improves player's capacity to communicate what their chosen actions will be; and second, it makes players commit to their words. During the pre-play phase, players publicly communicate their intended actions by choosing an action and publicizing it. However, players can change their chosen action only if and when a revision opportunity is awarded, and the action chosen at the end of the countdown is the action played. Thus, as the deadline approaches, players effectively commit to their chosen action. To separate the relative importance of each of these forces in promoting coordination on payoff dominant profile, we run a cheap talk treatment, in which the pre-play revision mechanism is non-binding. The results are discussed below.

First, we focus on the importance of communication—introduced in the cheap talk treatment—to achieve better coordination on the Pareto efficient profile. On average, cheap talk implies a significantly higher minimum effort than that of the baseline treatment, and the test of the null hypothesis of equal distributions of minimum efforts in these two treatments is rejected using a Komogorov-Smirnov test with $p < 0.01$. In addition, we test the null hypothesis

of equal distributions of effort choices in both treatments in all periods combined and separately for each period. A K-S test rejects the hypothesis with $p < 0.01$ for all periods pooled together and also, for separate periods after Period 5.

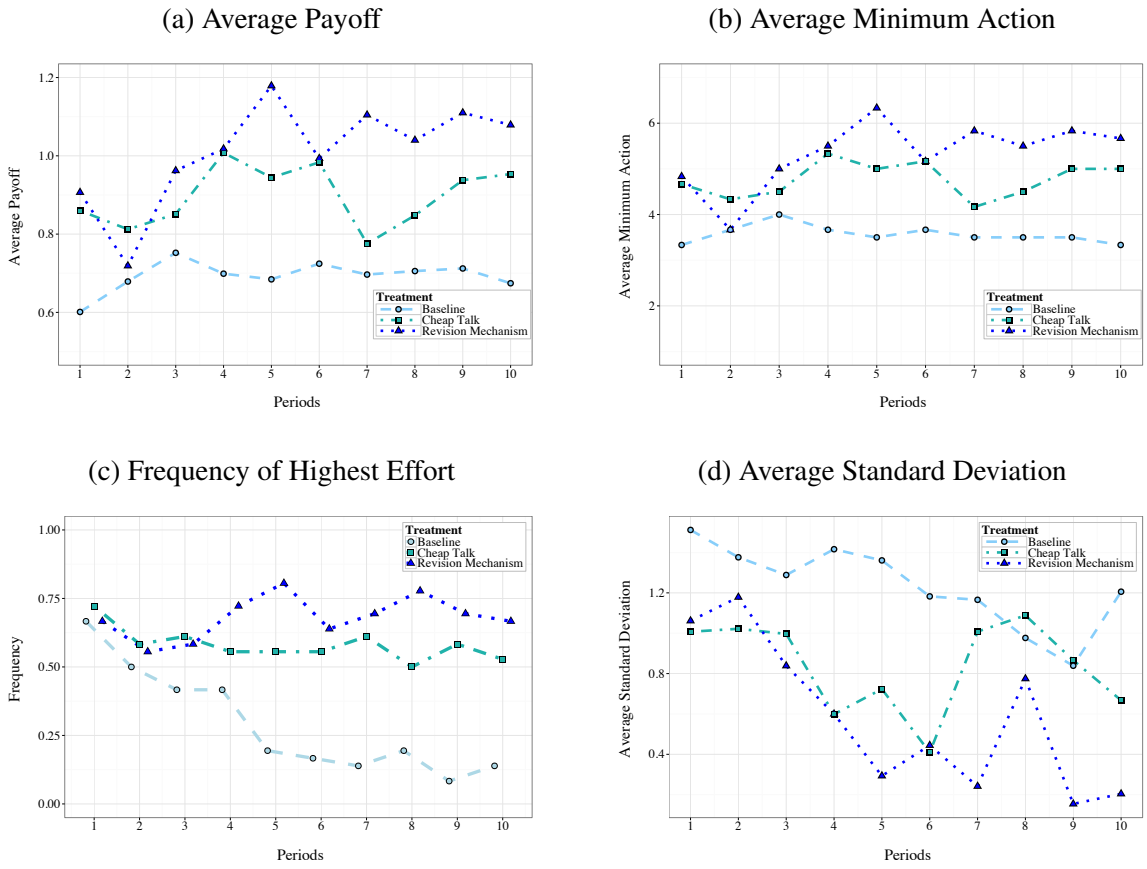


Figure 3: Treatment Comparisons

Communication among players—as introduced by the cheap talk treatment— significantly increases the minimum effort chosen (similar to the results of Blume and Ortmann (2007); more analysis on messages and final actions in cheap talk treatment can be found in Appendix E). This suggests that communication is, indeed, an important part of how the revision mechanism works to promote coordination on payoff superior outcomes. However, that answers only a part of our question; thus next, we assess the importance of the commitment. We begin by focusing on the average minimum action in each period, for each of our three treatments, displayed in Figure 3b. Although the average minimum action chosen

in the cheap talk is significantly higher than in the baseline treatment, it is also significantly lower than in the revision mechanism. Indeed, the test of the null hypothesis of equality of the average minimum efforts in revision mechanism and cheap talk treatments is rejected (MWU test, $p < 0.05$). In addition, the null hypothesis of equal distributions of minimum effort choices is also rejected (K-S test, $p < 0.05$). These differences suggest that commitment also plays an important role in increasing the minimum effort. In the rest of this subsection, we will present evidence that commitment increases the frequency of efficient effort and provides better coordination on any equilibrium. All these differences result in significantly lower payoffs in the treatment without commitment.

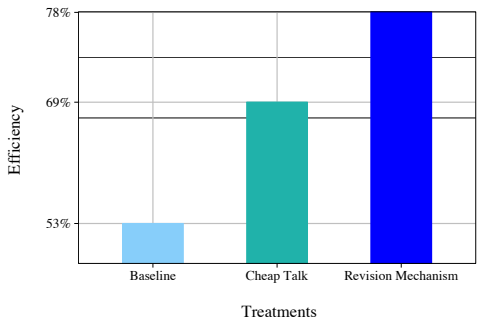
As presented in Figure 3c, all three treatments start the first period at the similar frequency of maximum effort (around 70%). However, the frequency with which the Pareto efficient equilibrium effort is chosen in the revision mechanism treatment starts dominating the other two treatments from period 4 and on. The frequency of highest effort in the revision mechanism is significantly higher than in the cheap talk treatment (MWU test, $p < 0.01$). Finally, we analyze how two treatments influence coordination on any equilibrium. The introduction of the revision mechanism drastically reduces miscoordination: the average standard deviation of actions decreases as periods progress (see Figure 3d) and in most of the later periods four out of six groups' standard deviation is 0. The average standard deviation of the actions played in the cheap talk treatments, reveals a different picture. Not only there is no clear declining pattern, but it does not seem to stabilize. Only two out of six groups managed to reach and keep standard deviation at 0. The difference in miscoordination in revision mechanism and cheap talk treatments implies that the former promotes a more stable coordination, further strengthening the significance of commitment.

We finish this subsection by comparing efficiency loss measured by the payoffs associated with each treatment. Efficiency loss encompasses the analyses done above, as both a smaller minimum action and players' miscoordination decrease payoffs. As noted before, the introduction of the pre-play revision mechanism more than halves (52.4%) the efficiency loss observed in the baseline treatment, while the similar gain from communication only is 33.7%, see Figure 4a. In Figure 4b, we present payoff ECDFs for all three treatments. The revision mechanism treatment induces significantly higher payoffs than the baseline treatment (K-S and MWU tests, $p < 0.01$), and it is also significantly higher than the payoffs in the cheap talk treatment (K-S and MWU tests, $p < 0.05$). In Appendix H, we analyze the

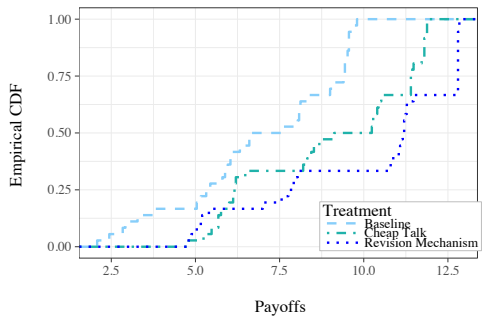
data clustering the errors at the group level and show that qualitatively the results remain the same.

Figure 4: Efficiency Comparisons

(a) Efficiency %



(b) Payoff ECDFs



The evidence presented in this subsection reveals the importance of both communication and commitment in increasing coordination on the better outcomes and thus, payoffs. This result highlights the implications associated with the revision mechanism: the introduction of communication with commitment promotes significantly more coordination than cheap talk alone.

5.2 On the Road to Coordination

In this subsection, we analyze subjects' revision decisions throughout the one-minute periods. We provide evidence that subjects use their revision opportunities to communicate with other subjects in order to coordinate on the best equilibrium.

There are two distinct ways a subject can use a revision opportunity to communicate with others. The first is whether to use the revision opportunity to change her posted action or not. Given that revision opportunities are public information, if the subject does not change her action, she communicates an intention. The second way a subject can communicate when she has a revision opportunity is by her choice of the revised action. Furthermore, the proof of Theorem A.2 from Calcagno et al. (2014) provides us with some intuition on how subjects should optimally communicate their intentions. The proof hinges on the intuition that—in an instant far removed from the deadline—if some players were not choosing the highest effort, then: (i) if a player choosing the highest effort had a revision opportunity, she would not change her action, and (ii) if a player not choosing the highest effort had a revision opportunity, she would revise her action to the highest effort.

We first present evidence that a subject's probability of revising her action is smaller when the subject is choosing a higher effort. Second, we take a closer look at the revised action. We report evidence suggesting that an important portion of the revised actions are forward thinking. Aligned with the theorem's intuition, we interpret these revisions as communication among players, trying to signal their intentions and influence each other's effort choices.

There were 476 total revisions available for each group during all the ten periods. On average, each subject received 7.93 revision opportunities per period. Subjects used 273 revisions in the main treatment; that is, 273 changes were made and posted on the graph.

We first analyze whether subjects revised their actions or not when they had the chance. We divide the revision opportunities in two. In the first group, the subject receiving the revision opportunity action is $e \in \{6, 7\}$, and is not the minimum effort in her group. In the second group, the subject receiving the revision opportunity action is $e \in \{1, 2, 3, 4, 5\}$, and is again not the minimum effort in her group. Aligned with the intuition in the proof of Theorem A.2 in Calcagno et al. (2014), the data suggests different behavior for the two groups. While subjects in the first group used only 8.4% of the received revision opportunities, the subjects in the second group revised their action four times more often — they used 33.7% of the revision opportunities.

We now proceed to analyze how agents chose to revise their actions. We take a more detailed look at subjects' behavior dynamics and we classify all the moves into five categories. Results are displayed in Figure 5. In addition, we look into individual revisions and players' typology in Appendix G.

(i) **Forward-Thinking:** moves that could decrease the payoff of the player, 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; (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 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 the move simply matching the group's minimum— as in (iii) Myopic Down.

(v) **Other:** moves decreasing the player's effort, when the subject was already at the group minimum. This category contains moves when subject decreases her effort choice, which could decreases the subject's own payoff, as she already was at the group minimum.

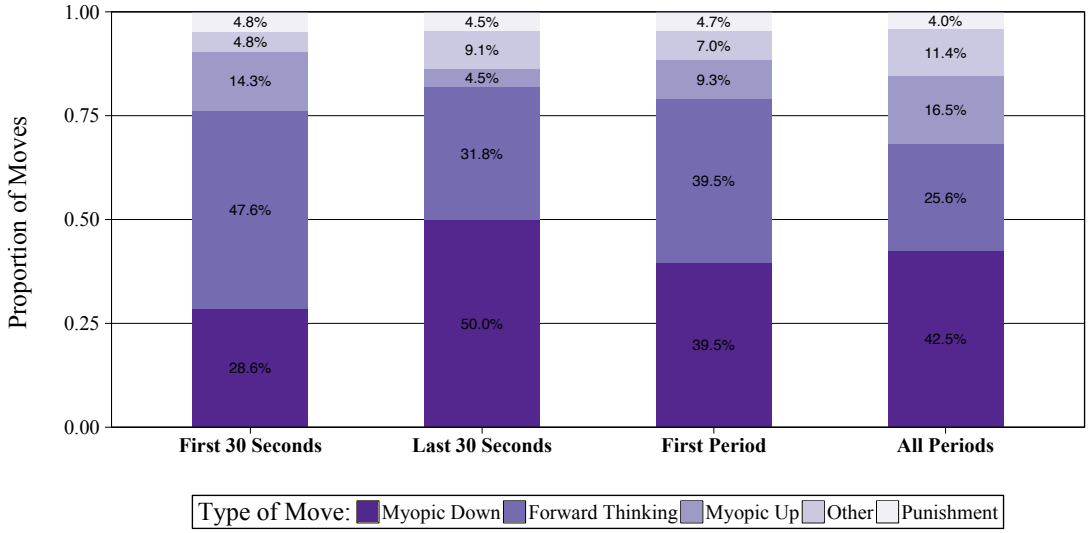
The first thing to note is that players consistently use revisions to communicate strategies and to influence other players' behavior. The main way in which players communicate through revisions is to use *forward-thinking moves* – myopically suboptimal effort level increases. These revisions would increase a player's payoff only if other players also move up their effort levels by the end of the countdown.[17] This process is at the core of the proof of Theorem A.2 in Calcagno et al. (2014). Aligned with that intuition we find that almost a half (47.6%) of the initial revisions are forward-thinking.

Among all periods, a quarter of the moves are forward-thinking, while almost 60% are myopic moves, with the majority of those being myopic down moves. However, if we focus on the first period, we see almost 40% of the revisions are forward-thinking, the same share as myopic down moves. The difference between the first round and overall revisions suggests that the communication embedded in the revisions plays a more important role at the beginning of the players' interaction, when there is more strategic uncertainty.

A second way that a revision could be used as a communication channel would be through punitive revisions, in which a player revises her effort down, below the minimum effort chosen by the group. This type of revision, however, is quite infrequent, as only 4% of the moves were punishments, which is 11 moves out of a total of 273. In line with previous studies, such as Andreoni et al. (2002), punishment strategies are infrequently used—and, in particular, less used than reward strategies—in order to foster cooperation. Note, however, that the lack of punishment in our setting could also be a result of a lower bound on effort

[17] This is similar to the idea of teaching other players how to play. The influence of "teachers" in leading to Nash play is studied in Hyndman et al. (2012).

Figure 5: Classification of All Revisions in Revision Mechanism



choices. If one of the group members chooses the lowest effort level, then there is no room for other group members to punish the subject, as they cannot move below the lowest effort level.

Table 3 presents the number of revision opportunities used by each group and their corresponding minimum efforts in the terminal period. Observe the inverted correlation between a group's last-period minimum effort and the number of revisions effectively made by that group. While the groups that have coordinated in the efficient equilibrium have made, on average, 26 revisions, players in the only group that coordinated in the payoff worst equilibrium revised their strategies 100 times. With that many revisions, it is apparent that the failure to coordinate on a more efficient equilibrium did not result from lack of trying to communicate.

Table 3: Number of Revisions per Group in the Revision Mechanism

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
Last Period Mins	7	1	7	6	7	6
# Revisions	43	100	28	78	6	18

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 (detailed analysis

can be found in Appendix F). In summary, we identify one subject as being unresponsive to the team members' actions or revisions and the choices of this subject seem to be the main driving force behind the group's failure to coordinate on the payoff-dominant equilibrium. This shows 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 period by choosing the efficient action and adjusted their actions at the end of the final one-minute countdown.

It is important to emphasize here that the groups that achieved efficiency did not choose the efficient outcome from the start. To the contrary, in no group did all subjects start with efficient actions, though five out of the six groups finished the game with the minimum action of 6 or 7. For example, in the first period, the minimum action of Group 6 was 1—the lowest possible effort; however, through a sequence of revisions the group managed to achieve efficiency by the end of the first period and earned 98.5% of the most efficient payoff.

6 Concluding Remarks

In this paper, we provide experimental evidence shedding light on how the introduction of an asynchronous revision pre-play phase increases the coordination on the Pareto dominant outcome in a minimum-effort game. As predicted by the theory, we show that the introduction of the revision mechanism significantly increases coordination on the payoff efficient outcome, and, thus, the subjects' payoffs increase significantly with such a mechanism. There are two distinct sources of payoff inefficiencies in the minimum game: first, players may choose an equilibrium profile that is Pareto dominated by other equilibrium profiles; and second, players may miscoordinate around such an equilibrium profile. Our results show that the introduction of communication and commitment to the minimum-effort game reduces inefficiencies on both dimensions. Not only is the minimum action chosen significantly higher than in the baseline treatment, but the standard deviation of the actions played is significantly lower.

In coordination games, both miscoordination and the coordination on suboptimal equilibria generate great efficiency loss. Consider the example of multiple firms simultaneously investing in a project, in which firms are to invest such that the investment level of a firm positively affects the payoff of the other firms. This paper suggests that the introduction of

a pre-play phase, following our mechanism, could significantly increase both the investment and the return to the firms. That is, the investment level in a coordination game can be improved by a third party—not by her investment, but simply by creating a more favorable set of rules.

The introduction of the communication and commitment phase — the revision mechanism — contributes to increased coordination in superior outcomes through two distinct forces. First, it allows players to publicly communicate their intended actions, and, second, it forces players to commit to their strategies as time passes since the likelihood of having a revision opportunity diminishes. In order to disentangle these two forces, we run a cheap talk treatment, in which players communicate but do not commit to their words. We first show that, as expected, communication is an important force for understanding how the revision mechanism works and significantly reduces the inefficiency when compared to the baseline treatment. However, communication is not the only force at play, and commitment also plays a crucial role. We show that the revision mechanism leads to significantly higher payoffs to the agents than the cheap talk treatment does. The interpretation of the revision mechanism as a policy suggestion is strengthened by the above separation. Even if pre-play communication occurs in real life in the form of negotiations, the introduction of commitment as signing a binding agreement at the end of these negotiations can further improve payoffs. Therefore, even if firms routinely discuss their investment strategies, the investment level and firm returns can still be increased by changing the environment in which the decisions are made.

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Appendices

A Proof of Proposition

We need to recall Definition 1 and Theorem 2 from Calcagno et al. (2014).

An action profile x^* is strictly Pareto-dominant if $u_i(x^*) > u_i(x)$ for all i and all $x \in X$ with $x \neq x^*$. A game is a *common interest game* if it has a strictly Pareto-dominant action profile.

Definition 1 *A common interest game is said to be a K-coordination game if for any i, $j \in I$ and $x \in X$,*

$$\frac{u_i(x^*) - u_i(x)}{u_i(x^*) - \underline{u}_i} \leq K \frac{u_j(x^*) - u_j(x)}{u_j(x^*) - \underline{u}_j}$$

where $\underline{u}_i = \min_x u_i(x)$.

Let the smallest value of r_i be $\alpha = \min_{i \in I} r_i$ and the second-smallest value of r_i be $\beta = \min_{\substack{i \in I \\ i \neq j^*}}$, where j^* is an arbitrary member of $\arg\min_{i \in I} r_i$.

Theorem 2 *Suppose that a common interest game is a K-coordination game with the strict Pareto-dominant action profile x^*, and*

$$(1 - \alpha - \beta)K < 1 - \beta$$

Then, for any $\varepsilon > 0$, there exists T' such that for all $T > T'$, in all revision equilibria, $x(0) = x^*$ with probability higher than $1 - \varepsilon$.

Now let us prove Proposition 1 using Theorem 2.

Proof. Rewrite the Theorem 2 condition:

$$1 - \min_{\substack{i \in I \\ i \neq j^*}} r_i - K(1 - \min_{i \in I} r_i - \min_{\substack{i \in I \\ i \neq j^*}} r_i) > 0$$

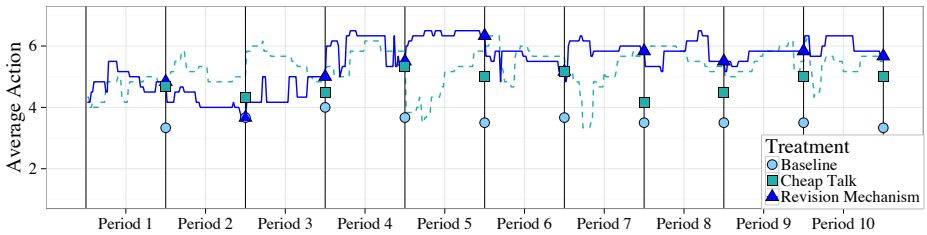
Note that LHS of the condition is maximized when revision opportunities are equal for all players $r_i = r_j = 1/n, \forall i, j \in I$—the second condition of Proposition 1. Substituting $r_i = r_j = 1/n, \forall i, j \in I$ into the condition above yields $K < \frac{n-1}{n-2}$.

The condition from Theorem 2 sets an *upper bound* on the common interest component $K < \frac{n-1}{n-2}$. Now let us rewrite the upper bound on K in terms of minimum game coefficients. To do so, recall that the minimum-effort game payoff function $\pi_i(e) = \gamma - \beta e_i + \alpha \min_{j \in I} e_j$. Using the symmetry of the payoff function, we can rewrite the K-coordination game definition as $\pi_i(x^*) - \pi_i(x) \leq K(\pi_j(x^*) - \pi_j(x))$ for any $i, j \in I$ and $x \in X$. The worst-case scenario is that all other players coordinate on some effort e, while one of the players chooses the maximum effort $e_{\max}$. In such a scenario, the expression can be further rewritten as $\gamma + e_{\max}(\alpha - \beta) - (\gamma - \beta e_{\max} + \alpha e) \leq K(\gamma + e_{\max}(\alpha - \beta) - (\gamma - \beta e + \alpha e))$ and simplified to $\alpha(e_{\max} - e) \leq K\left((\alpha - \beta)(e_{\max} - e)\right.$. Finally, we get $K \geq \frac{\alpha}{\alpha - \beta}$, which provides us with a *lower bound* on the coordination coefficient. Let us put together the upper bound and lower bound on K, $\frac{\alpha}{\alpha - \beta} < \frac{n-1}{n-2}$, which simplifies to $\alpha > (n-1)\beta$ — the first condition of our Proposition 1. ■

B By Second Data

In Figure 6, we have put periods and seconds on the x-axis and average minimum action on the y-axis.

Figure 6: Average Minimum Action



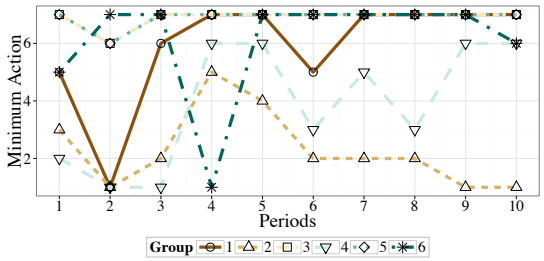
C Group Level Data

For all groups in three treatments we calculate the minimum effort in every period and the results are displayed in Figure 7. As we have seen from the aggregate results in Figure 2b, the

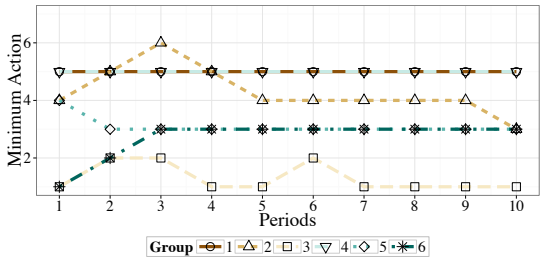
groups in revision mechanism treatment stabilize and achieve higher effort level compared to baseline and cheap talk treatments.

Figure 7: Group Minimums in Each Treatment

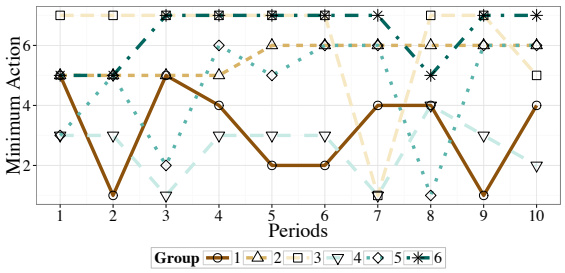
(a) Revision Mechanism



(b) Baseline Treatment



(c) Cheap Talk



D Choice vs Posted Action

In our paper, actions can be changed only when a revision opportunity is awarded; thus, in any instant there are two different data points per player: (i) the action the player is currently

committed to, which all the other players are observing;, and (ii) the action currently selected by the player. Only after a revision opportunity is awarded can the selected action become the action that the player is committed to.

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. In order to test that, we compare the last instant intended action with the action played. 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 agents would have been constrained in their choice process. However, we cannot reject the hypothesis of equal distributions of actions ($p > 0.1$), which indicates that the choice of interval length and revision frequency did not bind players' behaviors, thus aligning our experimental design with the conditions of Proposition 1.

E Cheap Talk: Last Message and Final Action

In every period of cheap talk treatment, subjects have sixty seconds to revise their action. However, after one minute countdown is over, screen appears where subjects choose their final action which is the only payoff relevant choice. We are interested in investigating how predictive are the last instant messages for the final action.

First, we simply aggregate all the information from all periods and groups in a histogram, see Figure 8. On average, in each period 67% of messages were truthful, that is 67% of subjects in each period chose the effort level that was posted in the 60th second of that period.

For more insight, we run a regression accounting for the group's minimum message, see Table 4. We find that both: subject's last message and her group's minimum message, are relevant for her final choice; however, the group's minimum message seems to be a better predictor. That is, subject is more likely to decrease her effort to the lowest message rather than follow through her intended action.

F Group 2 Dynamics

One of the six 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

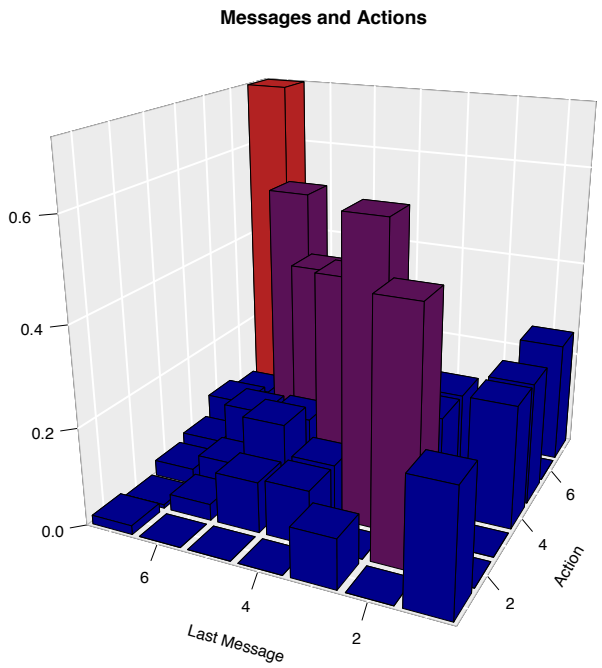


Figure 8: Last Message and Final Action

Table 4: Regression with Clustered Errors[a,b,c]

Final Choice	(1)	s.e.	(2)	s.e.	(3)	s.e.
60th Second Message	0.298***	(0.105)	0.330*	(0.181)	0.265***	(0.042)
60th Second Minimum	0.400***	(0.122)	0.341***	(0.129)	0.486***	(0.131)
Intercept	1.818***	(0.672)	2.064***	(0.764)	1.419	(0.985)
Observations	360		180		180	

[a] **Note:** (1) - all periods; (2) - first 5 periods; (3) - last 5 periods;
[b] **Note:** Standard Errors are clustered by Group;
[c] **Note:** Significance: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

actions and revisions over all periods and within them. In this group, three out of six group members began every period by choosing the efficient action and moved towards the group minimum later. Among the other three, two were responsive to the group members' actions and revisions, and only one subject did not seem to react to the information embedded in

other players' actions. In the first period, four out of six group members initially chose the efficient action, and the other two chose action 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' actions and revisions. Even though the group minimum at the end of the first period was 3, this subject started the second period by choosing action 2 and then switching to 1, although the minimum without this subject was 5. Moreover, in the fourth period, 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 action. 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 shows 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 period by choosing the efficient action and adjusted their actions up until the end of the final one-minute countdown.

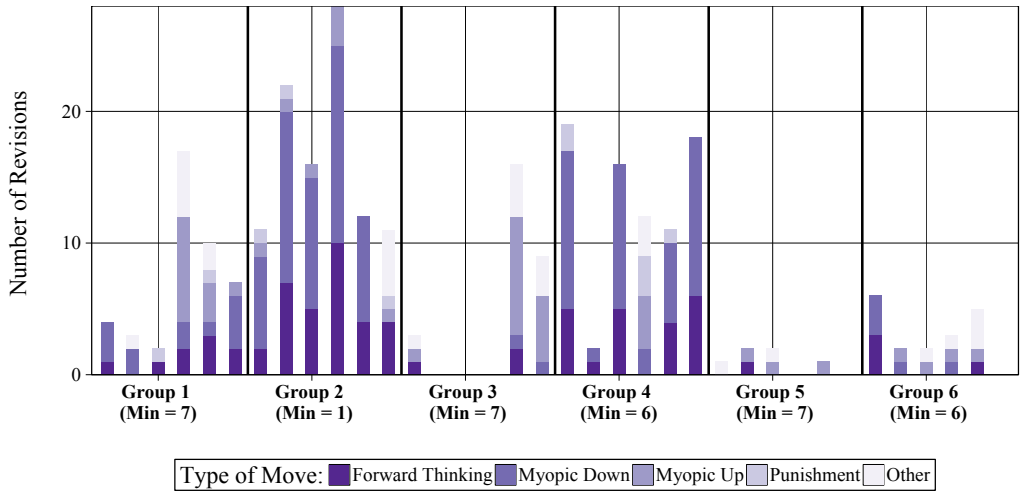
G Typology of Moves

In subsection 5.2 we classify revisions in various categories and identify the use of 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 on 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 7.58 revisions, the median number of revisions is 4.5. In Figure 9 we display the number of revisions each player has taken, and classify those revisions according to the same criteria used in subsection 5.2: a revision move may be forward-thinking, myopic up, myopic down, punishment, or other.

Figure 9 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, there are subjects making more than 15 revisions, and, in particular, one of them revising the action as many as 28 times. Note that members of Group 2, that coordinated on the payoff worst equilibrium, are well above the average and each have used more than 10 revisions.

Figure 9: Revision Histogram



As we classify each player's revision moves, Figure 9 indicates that players distribution of revision moves across those categories is quite similar. This indicates that players do not assume fixed roles within each group—one player as the forward-thinking, another as a follower, etc—instead, they all try to communicate their intentions through forward-thinking moves, and they all use the other types of revisions in similar proportions.

H Survey Results and Some Estimations

At the end of the experiment, our subjects took a short survey recording their gender, GPA, and whether they have taken a game theory course — summary is in Table 5.

Table 5: Survey Results

Variable:	%
Gender: Female	49%
Game Theory: Yes	22.2%
Self-Reported GPA	3.48

We run a regression with subject i's effort, e_i, as a dependent variable. As explanatory variables we have D_i and $\mathbf{Z}_i$, a categorical variable for treatment and a vector of subject

characteristics:

$$e_i = \alpha + \beta D_i + \Lambda \mathbf{Z}_i + \varepsilon_i,$$

where ε_i is the idiosyncratic error. We do not have enough data to do the analysis on session level but we cluster the errors by group.

For revision mechanism and cheap talk treatments we consider only payoff relevant efforts in order to compare it with the baseline treatment. We dropped the variable GPA, as a significant fraction of our subjects opted out from reporting it. We pooled the data from all the treatments and, in order to ignore the learning process, we only consider the last seven periods.

Table 6: Effort regression with clustered errors[a,b]

Effort	Coef.	s.e.
Revision Mechanism	1.4653**	(0.7441)
Cheap Talk	1.2592*	(0.6580)
Gender: Male	0.1056	(0.2608)
Game Theory: Yes	-0.0844	(0.2654)
Intercept	4.5846***	(0.4363)
Observations	756	

[a] **Note:** Standard Errors are clustered by group;
[b] **Significance:** * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 6 presents the results. We don't find a significant effect of gender or game theory course taken on effort choices and the treatment variable confirms the direction showed in the results section. Although we have a small number of independent data points, we still find a significant treatment effect of the revision mechanism.

We extend the analysis to consider subject i's payoff as dependent variable:

$$\text{payoff}_i = \alpha + \beta D_i + \Lambda \mathbf{Z}_i + \varepsilon_i,$$

where ε_i is the idiosyncratic error.

Table 7 presents the results. Again, gender or game theory course taken have no statistically significant effect on payoffs. The significance of the effect of the revision mechanism on payoffs is still present, while cheap talk has no significant effect.

Table 7: Payoff regression with clustered errors[a, b]

Payoff	Coef.	s.e.
Revision Mechanism	3.1754**	(1.5692)
Cheap Talk	2.0514	(1.4823)
Gender: Male	0.0003	(0.5848)
Game Theory: Yes	0.2477	(0.3035)
Intercept	6.9841***	(1.0682)
Observations	108	

[a] **Note:** Standard errors are clustered by group;
[b] **Significance:** * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.