Communication via Delay in a Coordination Game*

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Abstract

We propose a new communication protocol in binary-action coordination games with Pareto-ranked equilibria, which involves an option to delay. In the first period, players choose between committing to the risk-dominant (safe) action or delaying their choices. Players who wait then choose between the risk-dominant and payoff-dominant (efficient) actions in the second period. The delay option enables forward-induction reasoning, whereby a player's decision not to choose the risk-dominant action early signals an intention to choose the payoff-dominant action later. Assume that players have ϵ-social preferences, i.e., they help other players if at no cost to themselves. Iterated weak dominance then yields a unique strategy profile whereby each player waits and then chooses the payoff-dominant action if and only if everyone else waited, which leads to efficient coordination. In an experiment, most subjects adopt the unique iteratively undominated strategy, and, thus, the introduction of the delay option significantly promotes efficient coordination.

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1 Introduction

Coordination games are models of the challenge of coordination among economic (or other) players. Take a simple binary-action minimum-effort game, often called the weakest-link game, as an example. Each player can choose between low effort and high effort. Exerting high effort involves a cost to each player, while a player is paid based on the lowest effort exerted among all players.

The coordination challenge consists of two parts. First, there is the challenge of achieving a Nash equilibrium of the game. In the weakest-link game, there are two pure-strategy Nash equilibria – one in which all players choose low effort and one in which all players choose high effort. But miscoordination may occur if some players choose high effort while others choose low effort. The second challenge is to attain an efficient equilibrium, when equilibria in the game can be Pareto-ranked. In the weakest-link game, the efficient equilbrium is where all players choose high effort. However, in an experimental setting, Van Huyck, Battalio and Beil (1990) observe inefficiency in this game.

Can communication help bring about efficient coordination? To address this question, prior studies have typically added an initial stage to a coordination game, consisting of non-binding pre-play communication. See, for example, Charness (2000) for one-way costless communication, Cooper et al. (1992) for two-way costless communication, and Blume, Kriss and Weber (2017) for two-way costly but optional communication.

This paper explores a different form of communication that arises from the addition of a delay option to the game. Consider a complete-information binary-action minimum-effort game. The game unfolds in two periods: $t = 0, 1$. At $t = 0$, players can choose between "low" and "wait." The low choice is irreversible, so a player who chooses low at $t = 0$ is committed to that choice. This ability to make a binding choice distinguishes our model from those with cheap-talk communication, in which messages (announced choices) are non-binding.

By contrast, a high choice at $t = 0$ is reversible at no cost. (There is no discounting.) This is modeled via the option we give each player to announce at $t = 0$ that the player will wait until $t = 1$ to make their choice between low and high. At $t = 1$, each player who chose to wait observes a binary message d that reveals whether or not at least one player chose low at $t = 0$. Specifically, the message d takes the value

0 ("low") if at least one player chose low at $t = 0$ and the value 1 ("no-low") if all players chose to wait at $t = 0$. In a weakest-link game, if at least one player chose low at $t = 0$, then the payoff to a player does not depend on how many (other) players chose low. Therefore, a binary message structure is natural.[1]

The idea of our protocol is that a player who does not choose low at $t = 0$ should in some sense be signaling that they intend to choose high at $t = 1$. That is, there is a forward-induction (Kohlberg and Mertens, 1986) flavor to choosing wait. Intuitively, if a player intends to play low and secure the safe payoff, then they can do so right away, rather than wait and do so later, which cannot help them. Below, we spell out our analysis in more detail.

First, observe that if a player waits and then receives the "low" message, they will optimally choose low at $t = 1$. Formally, any strategy that involves choosing high after the "low" message is weakly dominated. Next, consider the situation in which a player receives the message "no-low." The game then enters a simultaneous-move subgame in which all players choose (irreversibly) between low and high. A player might decide to choose low in this subgame if they believe that at least one other player will do so. But notice that, in this case, the player in question chooses low after either message. Compare this with choosing low at $t = 0$. The two strategies yield the same payoff to our player for each strategy profile of the other players. But the first strategy may hurt the players who chooses high after observing "no-low." We assume that the players in our game have ϵ-social preferences. By this, we mean that each player has a payoff function that is their original payoff function plus an infinitesimal weight on a positively weighted sum of the other players' payoff functions. In other words, a player will not gratuitously hurt another player, where, by "gratuitously," we mean that one makes a choice that hurts others without helping oneself. Because ϵ is infinitesimal, there is no trade-off between a player's own payoff and those of other players. So, we do not assume altruism, but a weaker condition that can be called "considerateness."

Formally, we have just argued that, with ϵ-social preferences, the strategy of waiting and then playing low, regardless of the message d, is weakly dominated – on the second round of elimination – by playing low immediately (at $t = 0$). But

[1] Also, in a real-world weakest-link game with a large number of players, it could be difficult to monitor and learn the exact number of players who chose low at $t = 0$. For completeness, in section 2, we also examine the case in which each player sees the number of players who chose low at $t = 0$.

once this strategy is eliminated, the strategy of playing low immediately is weakly dominated by playing wait and then playing low after "low" and high after "no-low." In effect, by choosing wait, a player signals their intention to follow the message and, in particular, to choose high after "no-low." This is the sole strategy that survives iterated weak dominance, and the result is that all players choose "wait" followed by high effort, and efficient coordination is achieved.

There are two key components to this analysis. The first is forward induction, formalized as iterated weak dominance. The "money-burning" games of Ben-Porath and Dekel (1992) are a pioneering example of forward induction formalized this way. See the Literature section for other papers using this solution concept in models of coordination. Since elimination of weakly dominated strategies is order-dependent, we have to specify an order. We employ simultaneous maximal deletion (which is given an epistemic foundation in Brandenburger, Friedenberg and Keisler (2008)).

The second key component of our analysis is the inclusion of social preferences. See, for example, Fehr and Schmidt (2006) for a survey. We adopt a very weak form of social preference in which other players' payoff functions enter a given player's (original) payoff function only when the player is choosing between two equivalent strategies. Here, two strategies are equivalent for a player if, for every strategy profile of the other players, they yield the same payoff to that player. This particular concept of what we call "considerateness" should be contrasted with the usual models of altruism, which, in many games, will modify a player's original preferences in more ways than our condition does.

We also analyze the game via pure-strategy subgame-perfect Nash equilibrium,[2] and show that this solution concept does not lead to a unique prediction of efficient coordination, even with ϵ-social preferences. To see this, consider the subgame starting from the "no-low" message. If all other players choose low at this information set, playing high hurts a player without benefiting other players. Thus, ϵ-social preferences do not change the fact that playing low is the best response in this case. We conclude that subgame-perfect equilibrium does not rule out the case in which everyone waits and chooses low effort regardless of the $t = 0$ outcome.

In addition to a theoretical analysis of our coordination game with a delay option, we run experiments to see how effective this option is in bringing about efficient coordination. The experimental design follows the standard protocol in the experimental

[2]Throughout the paper, we focus on symmetric Nash equilibrium in pure strategies.

literature on the weakest-link games, as established by Van Huyck, Battalio and Beil (1990). Throughout a session, subjects are randomly matched into groups of four, and then play the game with the delay option for 15 rounds in each fixed group. We adopt the strategy method to elicit the subjects' full plans of play.

For comparison purposes, we also run the sessions for the original coordination game (no communication or delay option), the two-stage game in which initial choices of both low and high are non-binding (that is, the game with *a priori* meaningful cheap-talk messages), and the game in which an initial choice of high, but not low, is binding (the "opposite" of our game). In addition, we run a variation of our game with more information, in which each player observes the actual numbers of players who made initial choices of low and high rather than just the binary message d.

In our main treatment, where players can commit to low but not high effort at $t = 0$, we find that the majority of subjects trusted the "no-low" message, in the sense that, conditional on waiting and receiving this message, over 90 percent of the subjects chose high at $t = 1$. This confirms the theoretical finding that the "no-low" message is endogenously trustworthy.

On average, in each round, 75 to 85 percent of the subjects chose the unique strategy surviving iterated weak dominance - namely, waiting and then choosing high after "no-low" and low after "low." Because of the prevalence of this particular strategy, around 60 percent of the groups achieved efficient coordination. The frequency of efficient coordination did not decline over time. By contrast, the static treatment produced only 14 percent efficient rate,[3] which remained constant over time.

However, on average, approximately 10 percent of the subjects chose low after the "no-low" message in each round. This could reflect an absence of social preferences. Approximately 10 to 15 percent of the subjects chose to commit to low at $t = 0$, which could reflect a lack of confidence about others players' social preferences.

Providing information about the number of low and high choices at $t = 0$ added some complexity to the subjects' decisions, but it did not change the overall pattern of coordination. This is as expected since, as mentioned, the binary signal d already provided the subjects with payoff-relevant information.

Other communication protocols – namely, cheap-talk communication at $t = 0$ and an ability to commit to high but not low at $t = 0$ - also promoted efficient

[3]The efficiency rate of a round in a certain treatment is defined as the percentage of groups in which every group member's realized effort is high.

coordination, but the efficiency rates were, respectively, 18 and 33 percentage points lower, on average, than those in our mechanism with the binding low choice. In the case of cheap talk, where both low and high are non-binding at $t = 0$, the message that "everyone chose high at $t = 0$" was equally as trusted as the "no-low" message in the main treatment, but it occurred less frequently than the "no-low" message, which impairs the effectiveness of cheap talk.

The results of this paper can be interpreted in two ways. First, coordination games, in reality, are often played dynamically with naturally embedded delay options. Our study looks at the difference across commitment structures that delay options make possible, and identifies one particular commitment structure under which efficient coordination can be achieved.

Second, our results shed light on the design of mechanisms or institutional settings to promote coordination efficiency. Instead of changing the payoff incentives,[4] if the policy designer has control over reversibility of the strategies, then adding a simple delay option can significantly facilitate efficient coordination.

Consider a simple coordination game of investment played by multiple (three or more) players. Each player decides whether to invest (the efficient, payoff-dominant action) or not (the inefficient, risk-dominant action).[5] Let us first consider three different cases when a delay option is available.

In the first case, players can announce their choices early. However, these announcements are not binding in the sense that at a later date, after observing other players' announced choices, each player can freely decide whether to invest or not.

In the second case, players can decide between committing to invest early and waiting. If they wait, they can observe how many investments have been pledged earlier, and then decide between investing and not investing.

In the third case, players can make an early exit decision. Exiting the game is equivalent to committing to no investment, and is irreversible. Any player who does not exit the game can observe the number of exits (or whether anyone has exited) and then decide between investing and not investing.

Our experiment demonstrates that efficient coordination is more likely to occur in the third case than in the other two cases, and we provide theoretical grounds

[4] For previous studies on how to design payoff schemes to promote coordination, see Brandts and Cooper (2006*a*), Hamman, Rick and Weber (2007), and Sakovics and Steiner (2012).

[5] This game is essentially a weakest-link game if a successful investment requires all players to invest.

for this.[6] Thus, a policy designer who is interested in promoting investment should consider setting up the necessary institutions to implement a delay option with the commitment structure as described in the latter case.

Literature

The weakest-link (or minimum-effort) game studied in the experiment is a coordination game with Pareto-ranked multiple equilibria first proposed by Van Huyck, Battalio and Beil (1990). A large subsequent literature investigates how varying parameters of the stage game might affect coordination.[7] For example, Weber (2006) gradually increases the group size during the repeated play by adding new team members to the minimum-effort game. While Brandts and Cooper (2006*a*) vary the bonus parameters, Goeree and Holt (2005) vary the cost of effort.[8] Chen and Chen (2011) introduce social identity (via group-contingent social preferences) into the minimum-effort game and show how this can facilitate efficient coordination. While these papers vary parameters (sometimes dynamically) in the stage game and solve equilibrium selection via maximizing the stochastic potential function of the game (Monderer and Shapley, 1996), they do not incorporate an extensive structure into it.

Cooper et al. (1992) initiated a different literature by adding an outside option to the coordination games. Subsequent papers consider other pre-play moves, such as costly messages (Blume, Kriss and Weber, 2017) or pre-auctions (Cachon and Camerer, 1996; Van Huyck, Battalio and Beil, 1993), to minimum- or median-effort games.[9] We add what seems to be a natural feature to the stage game: an option to delay the risky choice. We think that this is likely a built-in feature of various real-world situations modeled as coordination.

In term of methodology, a common feature of papers (ours included) in this second literature is the use of forward-induction reasoning in the theoretical analysis. We formalize forward induction as the iterated elimination of weakly dominated strate-

[6] We also consider the case where players can commit to both investing and not investing, and they can also choose to wait at an early date. Please refer to Section 2.2 for a detailed discussion of different commitment structures.

[7] See Devetag and Ortmann (2007) for a survey.

[8] Brandts, Cooper and Fatas (2007) and Brandts et al. (2016) further look into the increased bonus case in which players have different costs of effort and in which low cost players could help the high cost players.

[9] Blume and Gneezy (2010) demonstrate that giving up the outside option could serve as a signal of ones' strategic sophistication, which is referred to as cognitive forward induction.

gies. By contrast, Blume, Kriss and Weber (2017) formalize it as an equilibrium refinement, in line with the original treatment in Kohlberg and Mertens (1986) and as further developed by Govindan and Wilson (2009).[10]

Our mechanism can be interpreted as a communication device. By choosing not to commit early to low, a player signals an intention to take the efficient action later. How pre-play communication would improve efficient coordination has been well studied in the literature. For examples, see Cooper et al. (1992), Charness (2000), Kriss, Blume and Weber (2016), and Blume, Kriss and Weber (2017) for communication in complete information weakest-link game.[11] Different from the existing studies, we consider large groups of players in which each player has the option of communicating an intention. More importantly, players communicate by delaying their choices instead of sending non-binding messages.

In our mechanism, only the risk-dominant (low effort) choice is binding at $t = 0$, while the payoff-dominant (high effort) choice is not binding.[12] We experimentally compare our mechanism with other commitment structures, but we restrict our attention to a simple extensive form in which players' early choices are either fully binding or not binding at all.[13] In a recent contribution, Avoyan and Ramos (2019) examine a "revision" mechanism, in which opportunities to revise earlier choices arrive stochastically within a time window. They provide experimental evidence showing that this dynamic structure with partial commitments significantly promotes efficient coordination. However, it is worth pointing out that the theory underneath efficient coordination in our paper - that is, forward induction formalized by iterated weak dominance - is quite different from that in Avoyan and Ramos (2019).

Another interpretation of our game is that players make an endogenous timing decision on when to commit to the binding action - namely, low. In this way, the paper also contributes to the literature on endogenous-move coordination games.

[10]Forward induction as the weakly iterated dominance argument is also examined in Battle-of-the-Sexes games and the entry games (see Cooper et al. (1993), Brandts and Holt (1995), Huck and Müller (2005), and Brandts, Cabrales and Charness (2007)).

[11]For studies beyond complete information coordination game, see Baliga and Morris (2002) for pre-play communication in a two-player coordination game with incomplete information, and see Avoyan (2018) for that in the global games setting.

[12]As will be discussed later, we refer to the action associated with the risk-dominant (payoff-dominant) equilibrium of the static game as the risk-dominant (payoff-dominant) action.

[13]Other extensive structures could involve partial commitment. Here, by "partial commitment," we mean that switching from the action chosen earlier to another one is costly or that the option of making such a switch is not always available.

(See, for example, Dasgupta (2007), Dasgupta, Steiner and Stewart (2012), and Basak and Zhou (2020)). While this literature considers mainly the incomplete-information world,[14] we study a two-period coordination game with complete information. In this simple game, we show that efficient coordination is achievable when players can choose the timing to commit to the risk-dominant action.

The remainder of the paper is organized as follows. Section 2 presents the static benchmark model and the theory of the dynamic protocol. The experimental design and procedure are discussed in Section 3. Section 4 reports the experimental results, and Section 5 concludes. Some of the proofs have been relegated to the Appendix.

2 Theory

There are $N \geq 2$ players, indexed by $i \in \mathcal{N} \equiv \{1, 2, \ldots, N\}$. Player i chooses an effort level $e_i \in E_i \equiv \{e_L, e_H\}$, where $e_H > e_L$. Choices are simultaneous. For a strategy profile $e = (e_i, (e_j)_{j \neq i}) \in \prod_{i \in \mathcal{N}} E_i$, the monetary payoff of player i is

$$\pi_i(e) = \alpha \min\{e_i, (e_j)_{j \neq i}\} - \beta e_i + \gamma,$$

where $\alpha > \beta > 0$ and $\gamma > 0$. In the literature, this game is referred to as the the weakest-link game or minimum-effort game.

In this game, if player i chooses low effort - i.e., $e_i = e_L$ - then their monetary payoff is $b \equiv (\alpha - \beta)e_L + \gamma$. Otherwise, if a player chooses high effort - i.e., $e_i = e_H$ − their monetary payoff simply depends on whether any other player chooses low effort. If all others choose high effort, then the player's monetary payoff is $c \equiv (\alpha - \beta)e_H + \gamma$; otherwise, the minimum effort is e_L and their monetary payoff is $a \equiv \alpha e_L - \beta e_H + \gamma$. Assuming that $\alpha > \beta$ implies that $a < b < c$. Table 1 depicts the payoffs.[15]

We assume that each player i has the following utility function:

$$u_i(e) = \pi_i(e) + \epsilon \sum_{j \neq i} \omega_{ij} \pi_j(e), \tag{1}$$

[14] An exception is Gale (1995), which considers a dynamic coordination game of investment in continuous time with complete information, in which players get flow payoff from their investment.

[15] In Table 1, the group minimum effort represents the minimum effort of all group members' choices, including the row player i.

		Group minimum effort	
		e_L	e_H
Player i's effort	e_L	b	-
	e_H	a	c

Table 1: Payoff structure

where ϵ is positive and infinitesimal, and w_{ij} are strictly positive numbers. We say that player i has an *ϵ-social preference*. Under this assumption, player i's preference is essentially lexicographic, in that there is no tradeoff between i's monetary payoff and that of any other player j. We will weaken this assumption in Section 2.2.

Proposition 1 *In this weakest-link game with binary actions, the pure-strategy Nash equilibria are $e_i = e_L$ for all i and $e_i = e_H$ for all i.*

Clearly, when players are egoistic ($\epsilon = 0$), there are multiple equilibria in this simple static coordination game. Proposition 1 confirms that the set of equilibria is the same with ϵ-social preference.

Coordinating on high effort e_H yields the highest payoff for all players, which is the efficient outcome, regardless of whether or not players have the social preferences as defined in (1). Hence, this is the *payoff-dominant equilibrium*, which we refer to as *efficient coordination*.

However, efficient coordination is not guaranteed since coordinating on the low effort constitutes another equilibrium. This is the *risk-dominant equilibrium* if $a + c < 2b$, or $\alpha < 2\beta$.[16] It is not miscoordination if all players decide on low effort. Rather, *miscoordination* occurs if players choose different levels of effort or, more precisely, when at least one player chooses e_H and at least one other player chooses e_L. Miscoordination incurs a significant loss to the players who choose e_H.

Next, we will look into a dynamic version of the weakest-link game in which players can decide whether and when to commit to low effort e_L.

[16] The global games approach, which allows a small perturbation of the complete-information structure in the coordination game, selects the risk-dominant equilibrium (see Carlsson and van Damme (1993) and Frankel, Morris and Pauzner (2003)). In our experiments (discussed later), we pick the parameter values to satisfy $\alpha < 2\beta$, which ensures that the low-effort equilibrium is risk dominant.

2.1 Dynamic structure with binding low action

There are two periods, $t = 0, 1$. Each player chooses between e_L and "wait" at $t = 0$. Players who choose e_L at $t = 0$ cannot make any further choices at $t = 1$. If a player decides to wait at $t = 0$, they can choose between e_L and e_H again at $t = 1$. In this sense, the choice of low effort e_L at $t = 0$ is a commitment.[17]

There is no cost associated with waiting. At $t = 1$, players who wait can observe whether someone chose e_L at $t = 0$. The strategy of i can be written as $s_i = (s_i^0, s_i^{10}, s_i^{11})$, where s_i^0 represents the choice at $t = 0$ and s_i^{10} (s_i^{11}) represents the choice at $t = 1$ when some (no) player chooses $s_j^0 = e_L$.

If $s_i^0 = e_L$, we write $s_i^{10} = s_i^{11} = \text{NULL}$. Otherwise, the player waits. For convenience, we write $s_i^0 = e_H$ for the choice of "wait."[18] There are two possible information sets that the game can reach if a player waits. We use d to denote the different states at $t = 1$, which is defined as

$$d = \mathbf{1}(\{j \in \mathcal{N} | s_j^0 = e_L\} = \emptyset).$$

Then, $d = 0$ ($d = 1$) if someone (no one) chooses e_L at $t = 0$, corresponding to the "low" ("no-low") message. Given a strategy profile $(s_j)_{j=1}^N$, the final effort level for player i is

$$e_i = \mathbf{1}(s_i^0 = e_L)e_L + \mathbf{1}(s_i^0 = e_H)s_i^{1d}.$$

In total, there are five pure strategies for each player i. For illustrative purposes, we write the set of pure strategies as $\mathcal{S} \equiv \{L, WLL, WLH, WHL, WHH\}$. The strategy of taking e_L at $t = 0$ ($s_i^0 = e_L$) is denoted as L. Otherwise, we write W for waiting at $t = 0$ (or $s_i^0 = e_H$). The second letter in any strategy associated with waiting indicates the effort level chosen after the "low" message ($d = 0$), and the third letter is for the effort level chosen after the "no-low" message ($d = 1$). For example, if a player takes strategy WHL, they will wait at $t = 0$ and choose high after the "low" message, and low otherwise.

Proposition 2 *For any $s_i \in \mathcal{S}$, the strategy profile $(s_i)_{i=1}^N$ constitutes a pure-strategy Nash equilibrium. The subgame-perfect equilibria are $(s_i = L)_{i=1}^N, (s_i = WLH)_{i=1}^N$,*

[17] Alternatively, one can think of this as an endogenous-move dynamic game, in which e_L (e_H) is irreversible (reversible). Players choose the time of committing to e_L between $t = 0$, $t = 1$, and never.

[18] Conceptually, waiting at $t = 0$ is the same as choosing the reversible action e_H at $t = 0$.

and $(s_i = WLL)_{i=1}^N$.

Proposition 2 demonstrates that, in this dynamic setting with binding action e_L and social preferences, multiple equilibria still arise. That said, choosing e_H in the subgame following the "low" message cannot be a part of an equilibrium in this subgame. Still, subgame perfection does not provide a unique prediction, as Proposition 2 states.

In the following proposition, we show that iterated simultaneous maximal deletion of weakly dominated strategies (Brandenburger, Friedenberg and Keisler, 2008) yields a unique strategy profile.

Proposition 3 *The unique strategy profile that survives iterated weak dominance is* $(s_i = WLH)_{i=1}^N$.

The argument involves three rounds of elimination, which can be tracked in a 2-player example (see Table 2). Below, we give the main argument for each step of elimination. Later, we show (in Proposition 6) that Proposition 3 generalizes from ϵ-social preferences to a bigger class of preferences that we call "considerate." The complete proof of Proposition 6 is in the Appendix.

		Player 2				
		L	WLL	WLH	WHL	WHH
	L	b, b	b, b	b, b	b, a	b, a
	WLL	b, b	b, b	b, a	b, b	b, a
Player 1	WLH	b, b	a, b	c, c	a, b	c, c
	WHL	a, b	b, b	b, a	b, b	b, a
	WHH	a, b	a, b	c, c	a, b	c, c

Table 2: 2-Player Payoff Matrix

Proof.

First Round (Eliminate WHL **and** WHH**)** WHL is weakly dominated by WLL. To see this, note that in the case of the "no-low" message, these two strategies yield equivalent outcomes. In the case of the "low" message, WHL involves choosing

e_H and yields a private monetary payoff $\pi_i = a$, while WLL yields a private payoff $\pi_i = b > a$. The same argument can be applied to show that WHH is weakly dominated by WLH.[19]

Second Round (Eliminate WLL) After the first round of elimination, the remaining pure strategies are L, WLL, and WLH. Regardless of what other players choose, the final effort choice under both strategies WLL and L is e_L. Thus, these two strategies yield the same payoff b to a player i.

Both strategies induce the same payoffs to the players $j \neq i$ in all except one case, in which all players $j \neq i$ choose to wait at $t = 0$, and at least some $j \neq i$ choose the strategy WLH. In this case, if player i chooses L, a player j who chooses WLH gets payoff b from the realized effort e_L. But player j's payoff is reduced to a if i chooses WLL because in this case, player j's realized effort is e_H, following the "no-low" message. Therefore, under the assumption of $\epsilon-$social preferences, L weakly dominates WLL.

Third Round (Eliminate L) Two strategies remain after the second round: L and WLH. If at least one player $j \neq i$ chooses L, the two strategies yield the same payoff to player i. However, if all $j \neq i$ choose WLH, then WLH yields a strictly higher payoff to i. Thus, L is weakly dominated by WLH. ■

In the dynamic game with binding low action, iterated weak dominance selects a unique outcome in which everyone adopts WLH and efficient coordination is achieved.

Theorem 1 *If all players choose the strategy of WLH, then the realized choice for everyone is high effort - i.e., $e_i = e_H$ - and efficient coordination is achieved.*

Proof. Given that all players choose WLH, we have $d = 1$, and, thus, for all $i \in \mathcal{N}$, $e_i = s_i^{11} = e_H$. ■

[19] The above dominance relationship holds for both $\epsilon = 0$ and $\epsilon > 0$. That is because, for any possible strategies that others take, both WHH and WLH would give them same payoff in both the cases of "low" and "no-low." For that reason, the elimination of the weakly dominated strategy does not rely on the assumption of a social preference.

2.2 Discussion

Before turning to the experimental design, we discuss how our result depends on the information structure, the commitment structure, and the assumption on agents' social preferences.

Full Monitoring

In our model, players who wait cannot observe the number of players choosing e_L at $t = 0$. This is a deliberate assumption meant to capture the difficulty in monitoring other players' choices on a team consisting of a large number of members. Instead, players who wait can observe only two possible messages: "low" and "no-low."[20] Here, we note the case where players who wait can observe the number of players who choose e_L (or wait) at $t = 0$.

If a player has already committed to low effort in $t = 0$, then efficient coordination cannot be achieved. Therefore, irrespective of how many others did so, the best response for any player who waited is to choose low effort. Thus, the binary information d already provides all payoff-relevant information. The following proposition confirms that the results in Proposition 3 and Theorem 1 hold true when more information is available.[21]

Proposition 4 *When the number of players choosing low at $t = 0$ can be observed, the unique strategy profile that survives iterated elimination of weak dominated strategies is $(s_i = WLH)_{i=1}^N$. Under this strategy profile, efficient coordination is achieved.*

To see experimentally how the availability of more information influences players' decision making, we design treatments (to be discussed in the next section) to examine the strategies that players take when they can observe the number of players who choose e_L at $t = 0$. We compare the results with the binary information treatments.

[20] Basak and Zhou (2020) explore the optimal history-dependent disclosure policy in a similar dynamic binary-action coordination game. In their model, the players do not have social preference, but they have incomplete information about the payoff-relevant fundamental. The authors show that binary information disclosure is one of the optimal disclosure policies.

[21] Abusing the notation, in the full monitoring case, we denote the strategy of waiting and then choosing high if and only if no one chooses low at $t = 0$ as WLH.

Structure of Commitment

Our result that efficient coordination can be achieved under iterated weak dominance relies on the assumption that low effort is the only binding choice at $t = 0$. However, one can certainly find real-world examples in which neither choice is binding, or in which high effort is binding while low effort is not. For example, one can think of a two-period investment game in which efficient coordination requires everyone to invest, and investing is the only binding choice at the first period.

No Binding Choices We first consider the case in which neither choice is binding at $t = 0$. In such a game, players choose between e_L and e_H at $t = 0$, and, after observing the choices at $t = 0$, they choose again between e_L and e_H at $t = 1$.[22] That is, the play at $t = 0$ is the costless pre-play communication, and the play at $t = 1$ is the actual coordination game.

Since a player's payoff depends only on their action at $t = 1$, their choice at $t = 0$ is payoff-irrelevant. For example, there is an equilibrium in which all players choose high at $t = 0$, and then choose low at $t = 1$, regardless of the information they observe. In another equilibrium, everyone chooses low at $t = 0$ and makes no change at $t = 1$, regardless of the information observed. Neither subgame-perfect Nash equilibrium nor iterated weak dominance provides any prediction as to whether the efficient outcome will occur.

Binding High-Effort Choice Now consider a coordination game in which high effort is the only binding choice at $t = 0$. Players first choose between "wait" and e_H at $t = 0$, and after observing the choices at $t = 0$, those who waited choose between e_L and e_H at $t = 1$.

The following proposition shows that there are multiple symmetric strategy profiles surviving iterated weak dominance. So, here as well, there is no prediction concerning efficient coordination.

Proposition 5 *In the game with full monitoring, in which high effort is the only binding choice at $t = 0$, neither iterated weak dominance or subgame-perfect equilibrium yields a unique prediction of efficient coordination.*

[22] In this discussion, we consider only the "full monitoring" scenario, in which players are able to observe all others' choices at $t = 0$. Moreover, as in the benchmark case, in which low effort is the only binding choice, there is no delay cost.

One might have thought that, in this case, efficient coordination is easier to achieve since players can make an early commitment to high effort and signal this to other players who wait. Even players who plan to choose low effort (though they cannot commit to this at $t = 0$), can change their minds and choose e_H. However, Proposition 5 demonstrates that this intuition is false.

Among all subgame-perfect equilibria, or the symmetric outcomes consistent with iterated weak dominance, efficient coordination is achieved either under the strategy profile in which all players choose e_H at $t = 0$, or under the profile in which all players choose e_H at $t = 1$ after observing no one chose e_H at $t = 0$. Any other subgame-perfect equilibrium predicts the inferior outcome.

The underlying mechanism for communication is quite different when high effort is the only binding choice. Players can communicate by committing to high effort at $t = 0$, and the message "Someone chose e_H at $t = 0$" is observed. But only when two players play the game is this message strong enough for one player to convince the other to choose e_H. With more than two players, only when all other players have committed to e_H is it optimal for a player to choose e_H at $t = 1$. In any other cases, players may choose e_L at $t = 1$, and they do this because they may think that some other players would do so at $t = 1$.[23]

Both Binding Choices Next consider a different commitment structure in which both low and high are binding choices at $t = 0$. There is also a wait option at $t = 0$, which enables players to choose between low and high at $t = 1$. The payoffs are determined at the end of $t = 1$, and there is no delay cost.

We will explore the cases both of binary message and of full monitoring. In the binary message case, players who choose to wait at $t = 0$ can only observe whether anyone has committed to low at $t = 0$, or not. In the full monitoring case, they can observe a fuller history of play at $t = 0$.

In this binary message case, different from the "binding low choice" structure, players are able to commit to high effort at $t = 0$. However, in terms of the binary message, high effort is no different from the "wait" choice at $t = 0$. It is easy to check that committing to high early is weakly dominated by waiting and then choosing high

[23] Whether players have the $\epsilon-$social preferences or not ($\epsilon = 0$) does not make a difference in this case. For any player, compared with choosing low at $t = 1$ or choosing high at $t = 0$, choosing high at $t = 1$ can either make her worse off without benefiting others, or make everyone better off.

after seeing no one chose low at $t = 0$. After eliminating the high effort choice at $t = 0$, the game is no different from the case of "binding low choice." As there, WLH is the unique iteratively undominated strategy and, as a result, efficient coordination is achieved.

In the full monitoring case, players who wait can observe the numbers of low, high, and wait choices at $t = 0$, and, if they choose to wait, they can choose either low or high contingent on any distribution of the time 0 choices. Clearly, any strategies involving the choice of high after observing low choices at $t = 0$ or the choice of low after observing all high choices at $t = 0$ are weakly dominated. After elimination of these dominated strategies, there is still a large residual strategy set due to the number of contingencies available for the choice at $t = 1$. In the online Appendix, we explore a three-player example of this game, and show that any remaining strategy survives iterated weak dominance. Thus, for example, players may choose to wait and then play low on observing that at least one of the other players waited, and efficient coordination is not achieved.

We see that when both low and high efforts are binding choices at $t = 0$, the effectiveness of the delay option depends on the information structure. The delay option does not guarantee efficient coordination with full monitoring.

In sum, the commitment structure is critical to coordination efficiency when a delay option is available. Based on our theory, we expect that efficient coordination will be achieved more frequently in games where low effort is the only binding choice, than in games with other commitment structures. We test experimentally the alternative commitment structures to distinguish our mechanism from other ones.[24]

Preference Structure

We assume that each player has an other-regarding social preference - namely, an ϵ-social preference. However, our results hold for significantly weaker assumptions on preferences.

[24] We chose not to run the experiment with both binding actions for the following reasons. First, the binary message setting in this case is very close to that in the "binding low choice" case since committing to the risky choice (or high effort) at $t = 0$ is clearly a dominated strategy. Second, in the "both binding choices" case, the full monitoring setting is too complex to be implemented with the strategy method. With four players, there would be ten different contingencies after a player has chosen "wait."

Here, we define a class of social preference orderings, which we call *considerate social preferences*.

Definition 1 *A social preference ordering* $\succsim$ *(complete and transitive) defined on* $(\pi_i, (\pi_j)_{j\neq i}) \in \mathbb{R} \times \mathbb{R}^{N-1}$ *is* ***considerate*** *if and only if*

1. $(\pi_i, (\pi_j)_{j\neq i}) \succ (\pi'_i, (\pi'_j)_{j\neq i})$ *when* $\pi_i > \pi'_i$ *while* $\pi_j = \pi'_j$ *for all* $j \neq i$*; and*

2. $(\pi_i, (\pi_j)_{j\neq i}) \succ (\pi'_i, (\pi'_j)_{j\neq i})$ *when* $\pi_i = \pi'_i$ *while* $\pi_j \geq \pi'_j$ *for all* $j \neq i$ *and* $\pi_{j_0} > \pi'_{j_0}$ *for some* $j_0 \neq i$*.*

Clearly, a player who values only their private payoff is not considerate. Note, too, that the definition of considerateness does not restrict the substitution rate between one player's payoff and others' payoffs. In fact, a player who is considerate does not necessarily sacrifice their own payoff to favor others. The ϵ-social preference defined in (1) is an example of no sacrifice and is a considerate preference.

Experimental evidence supports the presence of considerateness in social preferences. The data from the step-shaped choices sets in Fisman, Kariv and Markovits (2007) suggest that 81% of the subjects (43 out of 53) make decisions consistent with being considerate.

The following proposition states that as long as players are considerate, WLH is the unique strategy surviving iterated elimination of weakly dominated strategies.

Proposition 6 *Proposition 3 holds true when all players have considerate social preferences.*

The proof of Proposition 6 follows closely from the proof of Proposition 3 and is given in the Appendix. Specifically, the first step in elimination relies on the first condition of the definition of considerate social preference; that is, a player (weakly) prefers a strategy that can (possibly) increase their own payoff without reducing others' payoffs. The second step exploits the second condition of the definition: a player (weakly) prefers a strategy that can (possibly) increase others' payoffs while keeping their own payoff unchanged. The third step works because the strategy of WLH can (possibly) increase both the player's own payoff and others' payoffs.

Delay Costs

We have shown that forward induction reasoning works under considerate social preferences. A player who is considerate would prefer playing low at $t = 0$ than waiting and playing L regardless of the message received. In fact, even without social preferences, this result and the operation of forward induction reasoning would hold if there is a small cost of delay. If delay is costly, the strategy WLL yields a strictly lower payoff than L, regardless of other players' strategy profiles. Therefore, WLL is dominated by L in the presence of a delay cost.

However, when delay is costly, L is the unique best response when all other players choose L. Therefore, the strategy L survives iterated elimination of weakly dominated strategies. There is also an equilibrium in which all players choose L. Thus, delay costs may not help efficient coordination in our dynamic setting.

2.3 Summary

In the static weakest-link game, there are multiple equilibria, and efficient coordination need not be achieved. We go beyond this well-known result by considering a dynamic coordination game in which players have the option to delay their choices. In particular, players can make early commitments to low effort (risk-dominant choice). We show that delay can work as a tacit form of communication. All players choose to wait in order to generate the "no-low" message, and then, if this message is observed, they coordinate on the payoff-dominance equilibrium.

To examine our theoretical predictions, we run lab experiments to investigate individuals' decision making and the aggregate coordination outcome in our dynamic coordination game; and we make comparisons with other communication protocols in promoting efficient coordination.

3 Experimental Design

In the experiment, subjects played the above binary-action weakest-link game with parameters $N = 4$, $\alpha = 50$, $\beta = 40$, $\gamma = 35$, $e_H = 2$, and $e_L = 1$. Therefore, $a = 5$, $b = 45$, and $c = 55$.

Throughout a session, subjects played the games in fixed four-person groups repeatedly for 15 rounds, which is the standard protocol in the literature of weakest-link games, following Van Huyck, Battalio and Beil (1990).[25]

3.1 Main Treatments: Binary Information

Static Game ("St-B")

In "St-B" treatment, subjects play the the static weakest-link game discussed in Proposition 1. In this static game, subjects are informed of only the realized minimum effort in that round - i.e., low effort or high effort - at the end of each round. This limited feedback setting is referred to as binary information ("B" for short). It is the standard protocol in the minimum-effort literature, as opposed to the full monitoring protocol, which discloses the number of players who take a specific effort level.

Dynamic Game with Binding Low Action ("LB-B")

The "LB-B" treatment is our main treatment. It follows the dynamic structure proposed in Section 2.1 (see Proposition 2 and Proposition 3). Each round of the game consists of two periods. In the first period ($t = 0$), each player can choose between low effort and the wait option. If a subject chooses to wait at $t = 0$, they receive a *binary* message ("low" or "no-low"), saying that "someone (nobody) in the group has chosen e_L in $t = 0$." After that, the player can make the final decision on high or low effort.

We implemented the strategy method in all the treatments with dynamic games. Subjects need to make a decision for the first period, as well as the decisions conditional on all possible messages they receive at $t = 1$.

In all treatments with dynamic games, we adopt the term "binary information" ("B" for short) to mean that (1) subjects receive limited feedback at the end of each round (same as the static stage game); and (2) subjects who choose to wait can observe a binary message - whether someone chose low effort at $t = 0$ - before $t = 1$.

[25] Throughout the paper, we refer to the repeated play of the stage game as "rounds" and to the time $t = 0, 1$ in each round as "periods."

3.2 Additional Treatments

Full Monitoring Treatments ("St-F" and "LB-F")

In addition to the main treatments in which subjects receive feedback only about the minimum efforts in the previous round, we also tested the full monitoring versions of these two treatments: "St-F" (static, full monitoring) and "LB-F" (low binding, full monitoring). In all full monitoring treatments (static and dynamic), subjects are informed of how many group members chose low effort at the end of each round. When the stage game is a 2-period dynamic game, subjects who wait also receive the information on how many group members chose low effort at $t = 0$ (instead of the binary message).

More precisely, in the "LB-F" treatment, if a subject decides to wait at $t = 0$, they would face four possible situations: everybody waited, or 1, 2, or 3 group members chose low effort. Therefore, the subject's strategy would be to wait or not to wait at $t = 0$, and, if they waited, a full plan on these four contingencies.

We add these two full monitoring treatments for two reasons. First, in the binary information treatments, subjects might receive extra information in the "LB-B" treatment over what they would receive in the "St-B" one. To see this, consider the case in which a subject learns that someone chooses e_L at $t = 0$, and the subject also chooses e_L at $t = 1$. The subject could then infer that at least two subjects choose e_L in their group. However, in the static game with limited feedback, if a subject chooses e_L, there is no way for them to find out whether someone else also chooses e_L in that round. Since the information about the history of play in the earlier rounds might affect efficient coordination,[26] the full monitoring setting ensures a fair comparison between the static treatment and the dynamic one.

The second concern relates to the framing effect. In the "LB-B" treatment, subjects may feel tempted to choose differently for the "low" and "no-low" messages, thereby inducing more choices of WLH and WHL than of WLL and WHH. The full monitoring treatments with four contingencies should help to limit this framing effect.

[26] Van Huyck, Battalio and Beil (1990) find that full monitoring does not facilitate efficient coordination, while Brandts and Cooper (2006*b*) find that full monitoring improves coordination efficiency.

Alternative Commitments Treatments ("NB-F" and "HB-F")

We also tested two other commitment protocols on a stage game played dynamically in two periods, as discussed in Section 2.

We first considered the "NB-F" (neither action binding, full monitoring) treatment, in which both the choices of low effort and high effort at $t = 0$ were not binding. At $t = 0$, subjects chose between e_H and e_L. Then, at $t = 1$, upon observing the distribution of the choices in $t = 0$, they could freely switch to the other choice at no cost. The "NB-F" treatment is often referred to as *pre-play cheap talk communication*, because players' first-period choices can be regarded as non-binding announcements about their intentions. Testing the "NB-F" protocol allowed us to examine the effect of non-binding communication, as opposed to the the communication protocol in our main treatment.

The other protocol we considered was the "HB-F" (high binding, full monitoring) treatment, in which only the high effort choice was binding at $t = 0$. This protocol also allowed any player to credibly communicate to others their intention to choose high effort. However, as discussed in Section 2.2, there is no unique prediction of efficient coordination by SPNE or weak dominance. By testing the "HB-F" protocol, we could further understand how different ways of commitment and communication would affect efficient coordination, and the predictive power of iterated weak dominance.

3.3 Experiment Procedure

The experiment was implemented by a web-based program in the Smith Lab at Shanghai Jiao Tong University. At the beginning of each session, each subject arriving at the lab was randomly assigned a seat number. The program then randomly put them into groups consisting of four members, and the groups were fixed throughout the sessions.

We adopted a between-subject design. In each session, subjects played the games from one treatment for 15 rounds with their group mates. The choices were labeled "1" and "2" instead of "Low" and "High." There was no time limit for making the choices.

In the static treatment, subjects simply submitted their choices of "1" or "2" in each round. In the dynamic treatments, subjects' complete strategies were elicited using the strategy method. For example, on the choice page of our main treatment

(“LB-B”), subjects were first asked to choose between “1” and “Wait.” If the choice was “Wait,” then two additional choices would appear, asking them to choose an action for each of the two possible realizations of the message, “low” and “no-low.” Subjects were made aware that only one of the choices would be realized, based on the outcome in the first period. Instead, if any subject’s first-period choice was “1”, then there would be a notice telling them that they did not need to make any choice for the second period. However, the subject still needed to click a “confirm” button for each possible realization of the binary message to finish this round. With these two “confirm” buttons, the total number of clicks would be the same whether a subject chose to wait or not to wait at $t = 0$. Thus, subjects would not be able to infer others’ choices from the number of clicks.

In the full monitoring treatments, after choosing “Wait” (or any action in the “NB-F” treatment), the four possible outcomes from the first period would appear and the subject needed to choose an action for each of the four contingencies. If a subject chooses not to wait, then they needed to click on the four “confirm” buttons.

At the beginning of the experiment, the instructions were first read aloud in the lab. Then, the subjects completed a short comprehension test before the 15-round play of the experiment. After all participants finished the experiment, we gave them unincentivized questionnaires about their decision rules. Participants had not been informed about the questionnaires beforehand. At the end of each session, subjects were paid based on their cumulative payoffs from all rounds.

The numbers of subjects in each session and treatment are summarized in Table 3.

Treatment	# Sessions	# 4-player Groups
“St-B” (static, binary info)	5	21
“LB-B” (low binding, binary info)	5	21
“St-F” (static, full monitoring)	2	11
“LB-F” (low binding, full monitoring)	2	12
“NB-F” (neither binding, full monitoring)	2	12
“HB-F” (high binding, full monitoring)	2	12

Table 3: Experimental Design

4 Experimental Results

4.1 The Effect of the Delay Option in the Main Treatments

Result 1 (Group-level Efficiency) *The efficiency rates are significantly higher in "LB-B" than in "St-B," and the higher efficiency rates in "LB-B" could be sustained over time.*

The left panel of Figure 1 plots the frequencies of efficient outcomes in the "St-B" treatment and our main treatment, "LB-B." Efficient coordination was hard to achieve in the static games, which replicates the findings in the minimum-effort game literature. Only 15 percent of the groups managed to coordinate on high effort. This number stayed constant throughout the 15 rounds. This suggests that efficient coordination can be sustained in a single group only if the group starts by coordinating successfully on high effort from the first round.

In the "LB-B" treatment, the average rate of efficient coordination was over 60 percent. It started at 52 percent, and then gradually increased to 67 percent in the later rounds. This high rate of efficient coordination was sustained, except for a drop (to 52 percent) in the last round. The efficiency rate started at a significantly higher level in the dynamic games and was sustained, and it could even increase in the dynamic protocol with the binding low action.

Individual Payoffs How much did the higher efficiency rates contribute to higher individual payoffs? The average payoff in the static games was 42.4 per round, while it was 49.6 per round in the dynamic games. Given the fact that the highest possible payoff (when achieving efficient coordination) was 55, and the low effort choice secured a payoff of 45, the dynamic protocol with binding low action significantly recovered the efficiency loss in the static games. T-tests show that the differences in the payoffs between the two treatments were significant at the five-percent level in all but the 5th and the 15th rounds.

Realized Effort Choices To better understand the effectiveness of the delay option, we examine individuals' realized effort levels (see the right panel of Figure 1). In "St-B," although over 70 percent of the subjects showed their willingness to cooperate and started with high effort in the first period, the proportion of high choices

(a) Group: Efficiency Rate (b) Individual: Proportion of Realized e_H

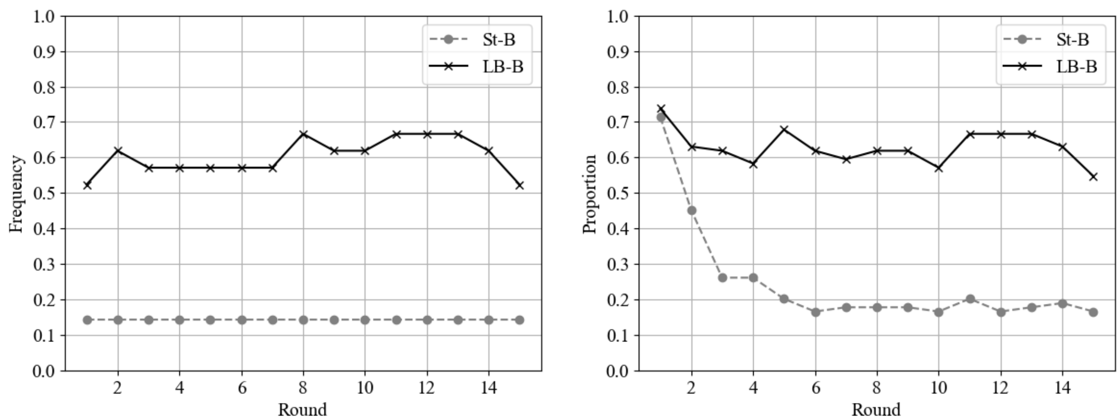

Figure 1: Group Efficiency and Individual Choices: LB-B v.s. St-B Treatments

Note: The left panel presents the percentage of groups that achieved efficient coordination in each round of play in both the "St-B" and "LB-B" treatments. The right panel presents the proportion of subjects who took high effort as the realized choice in each round of play in both the "St-B" and "LB-B" treatments.

dropped quickly, to below 20 percent within six rounds, and it never recovered.

In our main treatment ("LB-B"), the proportion of subjects whose realized effort choice was high started at 73 percent, which was very close to that in "St-B." But unlike the static treatment, the proportion in the "LB-B" treatment fluctuated over time, without a distinct decline. Hence, the rate of efficient coordination maintained a high level.

Miscoordination Rate When the delay option is not available, not committing to low effort early serves as a way to communicate among group members, which helps to promote efficient coordination and also to avoid miscoordination. Failing to achieve efficient coordination does not necessarily imply miscoordination, since coordinating on low effort can be an equilibrium in both the static and dynamic settings. Miscoordination happens when there is at least one subject whose realized effort choice is high, while some others take low effort. As shown in Figure 2, we checked whether all group members had the same realized effort levels at the end of each round. The rate of coordination was calculated as the percentage of groups in which all members had the same realized effort.

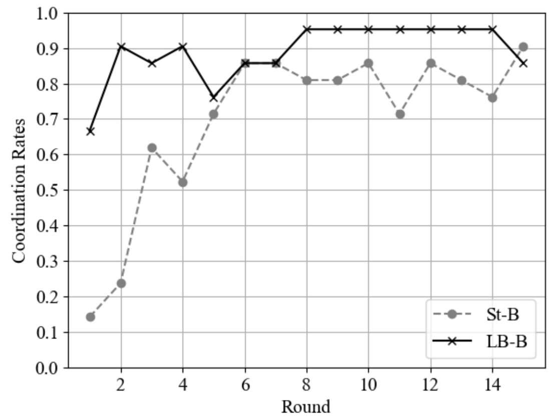

Figure 2: Group Coordination Rates

Note: The figure presents the proportion of groups in which all members have the same realization effort choice in each round of play in the "St-B" and "LB-B" treatments. The coordination rate is equal to 1 minus the rate of miscoordination

Interestingly, although the proportions of realized high choices were very similar in the two treatments in the first round, we observed that over 85 percent of the groups had miscoordination in the "St-B" treatment but only 35 percent had miscoordination in the "LB-B" treatment. The gap in the coordination rates also existed in the later rounds, despite the fact that many of the groups in the static treatment gradually converged to the low equilibrium. This suggests that the communication opportunity provided by the delay option had an important impact on coordination.

To understand the underlying difference in the coordination rates, one must consider the riskiness in the choice of high effort. In the static games, any low effort choice could incur a significant cost to those who chose high. Hence, the choice of high effort was very risky, and subjects tended not to take it if they lacked confidence in efficient coordination.[27] However, in the "LB-B" treatment, the strategy WLH was not that risky since the low effort choice at $t = 0$ would not incur any cost to the WLH choosers, even though it would break the efficient coordination. In this sense, the dynamic protocol with binding low action allowed the players to communicate and coordinate in a less risky way.

[27] Recall that, based on our parameters, subjects taking high effort would suffer a great loss, by getting only 5 instead of 45 (payoff for low effort) or 55 (payoff for the efficient outcome).

Result 2 (The Adoption of Strategies) *In "LB-B," more than 70 percent of the subjects took the strategy WLH, which was the unique strategy surviving iterated weak dominance.*

Proposition 3 and Theorem 1 imply that the "LB-B" protocol facilitates efficient coordination because WLH is the unique strategy that survives iterated weak dominance. However, as shown in Proposition 2, other strategies (e.g., L and WLL) can constitute symmetric SPNEs. The strategy method allowed us to test the predictive power of weak dominance by examining a decomposition of the strategies adopted in the "LB-B" treatment. Figure 3 plots the distribution of strategies L, WLL, WLH and the dominated strategies (WHL and WHH) adopted by subjects as the experiment went on.

Consistent with the prediction of weak dominance, most subjects adopted the strategy WLH. The proportion of WLH choices was 85 percent in the first round, suggesting a high willingness to wait and cooperate if all group members made the same positive gesture.[28] If any group member adopted the strategy WLL, subjects who chose WLH would end up with a payoff of 5 instead of a secured payoff of 45 under the strategy L or WLL. In our experiments, subjects could identify whether the adoption of WLL was the (pure) reason for no efficient coordination in the group via the feedback after each round. That explains why the proportion of WLH dropped slightly over time and ended up at 75 percent in the last round.[29]

Aside from the WLH choosers, we had 15 percent choosing L and 10 percent choosing WLL, on average, over time. In particular, there is an increase in the proportion of the subjects choosing L, from 7 percent in the first round to over 15 percent in the later rounds, possibly due to the failure of efficient coordination in the previous rounds.

Adopting strategies other than WLH can be understood within the framework of our theory. In the model, the iterated elimination of weakly dominated strategies relies on the fact that players have considerate social preferences and believe in others'

[28]There is a gap between the proportion of the WLH strategy (85% in the first round) and the proportion of having high effort as realized actions (73% in the first round), which is due to the presence of some group members choosing L in the first period. In this case, the realized action for the WLH strategy would be low effort.

[29]An analysis of individual choices (see part C in the online Appendix for details) and the questionnaires reveal that some participants who started with WLH switched to L or WLL because they were hurt by their group mates who chose WLL.

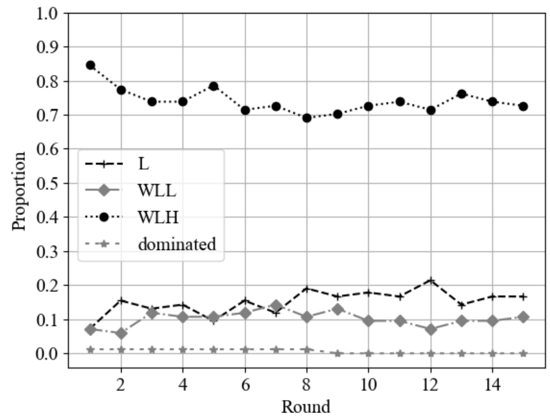

Figure 3: Decomposition of Strategies in the "LB-B" Treatment

Note: The figure presents the frequency of different strategies chosen by subjects in each round of play in the "LB-B" treatment. "dominated strategy" denotes the strategy of WHL and the strategy of WHH, which are strictly dominated strategies in the first round of elimination.

social preferences, as well. A subject choosing L over WLL might suggest that they had a social preference to not hurt others, but did not believe in the social preferences of their group mates. Therefore, they did not finish the last round of elimination. For the 10 percent of subjects choosing WLL, one plausible explanation would be selfish or spiteful social preferences.

We collected subjects' self-reported motives for choosing a certain strategy from the survey after the experiment. The survey was unincentivized and anonymous, and served only as a piece of anecdotal evidence. The results from subjects who chose WLL show that most of them, indeed, had these negative social preferences, but that some of them were also confused and failed to realize that adopting the strategy of WLL could have hurt others (compared with the strategy L).[30]

Apart from the negative consequence that WLL can impose on other subjects, there is a subtle difference between WLL and L. In fact, in the binary information treatment, WLL could help subjects to get more information, compared with L. In the survey, some subjects who chose WLL claimed that they decided to choose L anyway, but choosing WLL allowed them to see whether someone else would also

[30]Some participants explicitly mentioned that they chose WLL to hurt other subjects or to retaliate against the teammate who chose WLL, which suggests negative reciprocity and the opposite of social preference.

choose L in the first period. This motive suggests that waiting and acquiring information might have provided some extra utility for some subjects and that they did not mind hurting others in order to get this information. Thus, to control this for incentive of learning, it is worth investigating cases in which subjects can observe the full history of play. Next, we report the experimental findings for the full monitoring treatments.

4.2 Full Monitoring

Result 3 (Group-level Efficiency) *The efficiency rates were significantly higher in the dynamic treatment with full monitoring (i.e., "LB-F") than that in the static treatment with full monitoring (i.e., "St-F"), and the higher efficiency rates in "LB-F" could be sustained over time.*

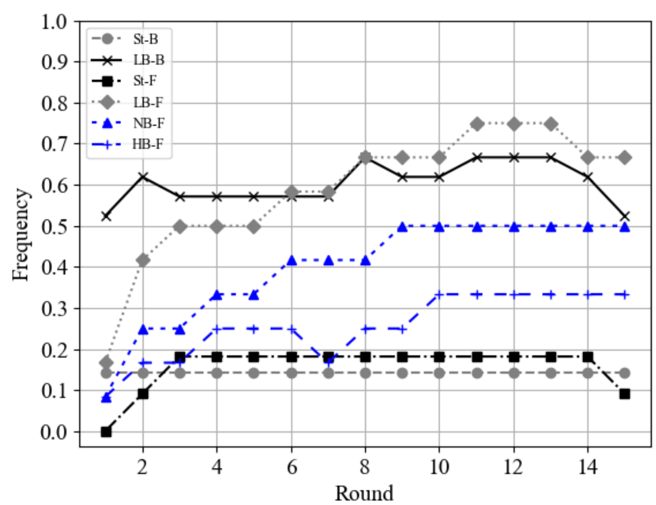

Figure 4: Efficiency Rates: All Treatments

Figure 4 presents the efficiency rates in all treatments. In "St-F" and "LB-F", more subjects started with low choices in the first round.[31] In fact, the lower initial

[31]The pattern of the increasing group minimum efforts in the first couple of rounds is also present in Avoyan and Ramos (2019) and Brandts and Cooper (2006*a*). In the treatments with full monitoring, subjects can observe the exact number of low and high effort choices in the previous rounds, which might facilitate coordination. For example, if a subject realized that they are the only one playing low in one round, they might want to switch from low to high in the next round.

efficiency rates could be observed in all of the full monitoring treatments. One explanation could be that some subjects were confused by the four contingencies and, therefore, chose the most conservative strategies at the beginning of the experiment. But the rate of efficient coordination quickly converged somewhere above the binary information treatments, though the differences were, in general, not significant. Therefore, we still observed a significantly large difference between the static and dynamic treatments with full monitoring. This suggests that the different efficiency in the "St-B" and "LB-B" are not caused by the possible extra information available in the "LB-B" treatment.

Result 4 (The Adoption of Strategies) *Over 60 percent subjects adopted the strategy equivalent to WLH in "LB-F". More subjects adopted the dominated strategies in the full monitoring treatment (compared with the binary information treatment).*

We next investigate the strategies chosen in the "LB-F" treatment. As depicted in Figure 5, in the earlier rounds, about 60 percent to 70 percent of the subjects chose the strategy WLH. This proportion is lower than that in "LB-B."[32] However, the proportion of those choosing WLH rose quickly in the later rounds and came very close to that in the "LB-B" (around 75 percent), suggesting that the high adoption rate of the WLH strategy was not likely driven by the framing effect of the binary information.

As discussed above, implementing the strategy method in full monitoring treatments turned out to be more challenging because it required subjects to decide on a full menu for all four possible contingencies after waiting at $t = 0$. About 10 percent of the subjects used some dominated strategies at least once in the first 5 rounds, whereas this proportion is merely 1 percent with binary information. In addition, they did not learn to avoid using these dominated strategies till the end of the experiment.[33]

[32]Recall that the WLH strategy in "LB-F" is defined as "wait in the first period; choose e_H if nobody chooses e_L in the first period, and choose e_L if 1, 2 or 3 subjects in the group choose e_L in the first period." Any strategy involving choosing e_H after someone chose e_L at $t = 0$ is called a dominated strategy.

[33]But it should also be noted that everyone in the binary information treatment learned to avoid the dominated strategies, even for those in the groups with efficient coordination. Another possibility is that, since these subjects belong to the groups that achieved efficient coordination, adopting the dominated strategy does not cause any harm to their payoffs.

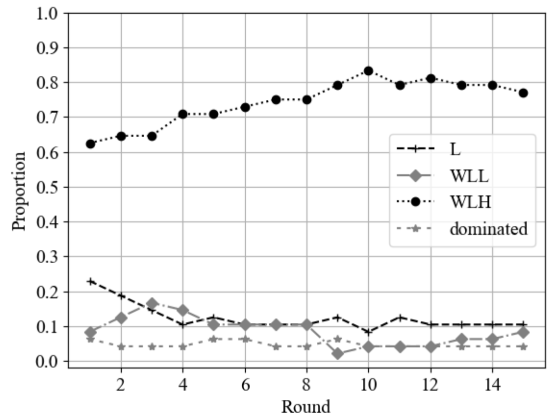

Figure 5: Decomposition of Strategies in the "LB-F" Treatment

4.3 Alternative Commitment Protocols

Result 5 (Group-level Efficiency) *The efficiency rates in both "NB-F" and "HB-F" treatments were significantly higher than those in "St-F" but significantly lower than those in "LB-F."*

In Figure 4, we also plot the efficiency rates in the games in which neither action was binding ("NB-F") or where only the high action was binding ("HB-F"). We find that the "NB-F" treatment, or cheap talk pre-communication, indeed raised efficient coordination significantly. Having the opportunity to communicate one's intentions in playing promoted coordination in the common interest coordination games, a finding consistent with those in the literature (Avoyan and Ramos, 2019; Blume and Ortmann, 2007; Blume, Kriss and Weber, 2017). However, the efficiency rates in the "NB-F" protocol were significantly lower than in the "LB-F" protocol. Chi-square tests confirm that, compared with "NB-F," the "LB-F" protocol generated a significantly higher efficiency rates in all rounds of play.[34] On average, "LB-F" raised the efficiency rates by 18 percent points. Compared with "NB-F," this is a 40 percent increase.

To better distinguish the effect of communication - via delay from cheap talk com-

[34]Given that the subjects could observe all information about the $t = 0$ choices, we believe that "LB-F" is a better comparison for "NB-F" than "LB-B." However, if we compare "NB-F" with "LB-B" (our main treatment), the differences in the efficiency rates are still significant in all but the last round.

(a) $t = 0$ choices: Wait or High

(b) Effectiveness of "no-low" and "all-high"

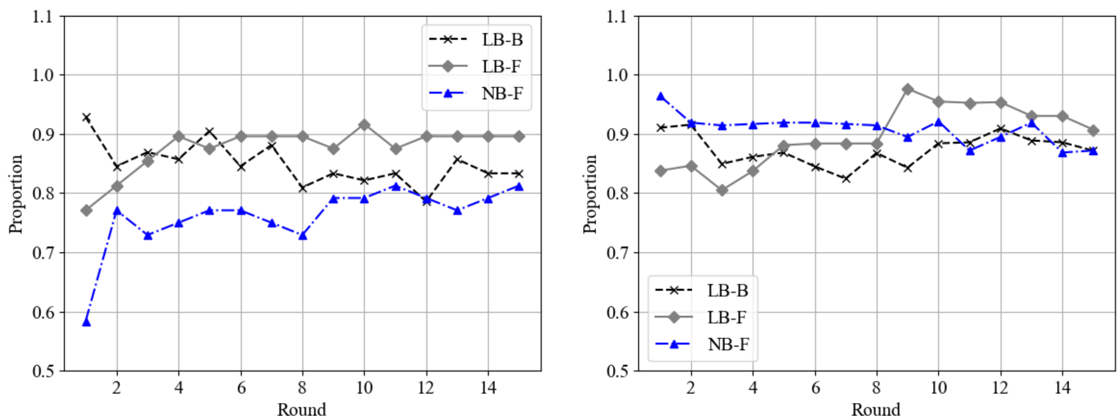

Figure 6: Comparison of the "no-low" and "all-high" messages

Note: The panel on the left shows the frequency of the "wait" choice at $t = 0$ in the "LB-B" and "LB-F" treatments, and the frequency of the "e_H" choice at $t = 0$ in the "NB-F" treatment. The panel on the right shows, among the subjects who waited, the proportion of those who choose e_H after the "no-low" (in the "LB-B" and "LB-F" treatments), and the proportion of subjects who choose e_H after the "all-high" message (in the "NB-F" treatment).

munication in promoting efficient coordination - we further examine the effectiveness of certain messages by looking into the subgame at $t = 1$. In particular, we compare the strength of the "no-low" message in the "LB-B" and LB-F" treatments to that of the "all-high" message (i.e., all others chose e_H at $t = 0$) in the "NB-F" treatment. Figure 6 summarizes our findings.

As the right panel of Figure 6 shows, the "all-high" message was effective in fostering high choices in $t = 1$. It is comparable to (or even slightly more effective than) the "no-low" message in the "LB-B" and "LB-F" treatments. Recall that the "no-low" message simply means that "all subjects choose to wait at $t = 0$" or "nothing has happened yet." In fact, all messages in the cheap talk case have that meaning since all actions are reversible. However, the "all-high" message, by its face value, says that "nothing has happened yet, but all subjects intend to choose the high effort."

If the face value of messages can make a difference in affecting economic players' beliefs and their subsequent moves (not in a strategic sense but in a linguistic sense), it would be surprising that the "no-low" message could be as effective as the "all-high" message.

Based on our theory, the "no-low" message delivers precisely the intention "all subjects would choose e_H at $t = 1$." The theoretical prediction is more than the trustworthiness of the "no-low" message for the subgame starting from $t = 1$. It also predicts that all subjects will choose to wait at $t = 0$ and, thus, generate the "no-low" message. That is how efficient coordination is achieved. As in the left panel of Figure 6, experimental evidence confirms this prediction. The frequency of wait choices at $t = 0$ in "LB-F" was significantly higher than that of first-period e_H choices in "NB-F," and, because of this, the "no-low" message was more frequently generated. This explains why communication via delay (the "LB" protocols) was more effective than cheap talk pre-communication (the "NB" protocol) in promoting efficient coordination.

"HB-F" Treatment When high effort is the only binding choice at $t = 1$, as discussed in Section 2.2, neither SPNE nor weak dominance can provide a clear prediction about efficient coordination. Although choosing high effort early may serve as a signal to induce the players who have waited to follow, it is, indeed, a very risky choice because all the subjects who wait still face a coordination problem at $t = 1$.

The experimental evidence shows that the "HB-F" protocol could promote efficient coordination (compared with the static benchmark with full monitoring), but the efficiency rates are, on average, 33 percentage points lower than that in the main treatment. On average, only 15 out of the 48 subjects chose e_H in $t = 0$ in each round. Out of the subjects who chose to wait, only 80 percent chose e_H if all other group mates had already committed to e_H, and only 33 percent would e_H if two of the other three group mates had committed to e_H.

4.4 Summary

Overall, the experimental evidence supports our theoretical prediction that efficient coordination can be achieved in a two-period minimum-effort game in which low effort is the only binding choice in the first period. The strategy of waiting and then choosing high effort if all others waited is adopted by most subjects in both the binary information and full monitoring treatments. The evidence also provides some support for the underlying mechanism of efficient coordination - that is, the trustworthiness of the "no-low" message for the subgame at $t = 1$ and all subjects' coordination at $t = 0$

to generate this trustworthy message. In addition, the evidences from the experiment suggests that it is not only the opportunity for communication (or dynamic play), but also the manner of communication (or commitment structure associated with the delay option), that matter for the improvement in coordination efficiency.

5 Conclusion

In this paper, we study a simple coordination game – a weakest-link game with binary choices. We offer a theory, as well as experimental evidence, to suggest that adding a delay option to the static game can help solve the coordination problem.

The delay option allows players to wait and see the past actions taken by the other players. Such a learning opportunity is also available when players move in an exogenous order. In that case, a standard backward-induction argument shows how efficient coordination may be achieved. Instead, with the delay option, players can effectively move endogenously in time, and, thus, the mechanism in this paper involves more than just learning the past actions.

The delay option enables forward-induction reasoning to operate in the extended game. Interestingly, giving up the "outside option" of committing to the risk-dominant action right away signals an intention to take the payoff-dominant action later, if all other players wait. To be more precise, we have seen that this is true, provided that players have *considerate* social preferences. We formalize this intuition via iterated weak dominance and show that efficient coordination is the unique resulting outcome, even though other outcomes can arise as subgame-perfect Nash equilibria.

The evidence from the lab experiment is consistent with our theoretical prediction. In all rounds of our experiment, more than 70 percent of the subjects played the unique strategy that survives iterated weak dominance. Our mechanism significantly improved efficient coordination, reduced the rate of miscoordination, and increased the subjects' payoffs, as compared with the static treatment or other dynamic treatments with different communication protocols.

The main lesson from this study is that an opportunity for delay is a form of a tacit communication that works by signaling an intention concerning future moves. We think that this idea should be applicable to more-complex coordination settings, as well as to other strategic interactions beyond pure coordination. We leave this to future studies.

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Appendix

Proof of Proposition 1 Consider player $i \in \mathcal{N}$. When all other players take $e_j = e_L$, their monetary payoffs will be $\pi_j = b$ (for all $j \in \mathcal{N} \setminus \{i\}$), which is independent of player i's choice. For player i, choosing $e_i = e_L$ yields $\pi_i(e_i = e_L, (e_j = e_L)_{j \in \mathcal{N}\setminus\{i\}}) = b$, while choosing e_H yields $\pi_i(e_i = e_H, (e_j = e_L)_{j \in \mathcal{N}\setminus\{i\}}) = a$. Since $b > a$, $u_i(e_i = e_L, (e_j = e_L)_{j \in \mathcal{N}\setminus\{i\}}) > u_i(e_i = e_H, (e_j = e_L)_{j \in \mathcal{N}\setminus\{i\}})$, and, thus, $\{e_i = e_L\}_{i=1}^N$ is a Nash equilibrium.

Similarly, when all others are taking $e_j = e_H$, choosing $e_i = e_H$ yields the same monetary payoff c for player i and all other players - i.e., choosing $e_i = e_L$ yields $\pi_i(e_i = e_L, (e_j = e_H)_{j \in \mathcal{N}\setminus\{i\}}) = b < c$ for player i and $\pi_j(e_i = e_L, (e_j = e_H)_{j \in \mathcal{N}\setminus\{i\}}) = a < c$ for all $j \in \mathcal{N} \setminus \{i\}$. Hence, $u_i(e_i = e_H, (e_j = e_H)_{j \in \mathcal{N}\setminus\{i\}}) > u_i(e_i = e_L, (e_j = e_H)_{j \in \mathcal{N}\setminus\{i\}})$, and, consequently, $\{e_i = e_H\}_{i=1}^N$ is a Nash equilibrium. $\square$

Proof of Proposition 2 Consider player i's choice when all others take $s_j^0 = e_L$. In that case, $d = 0$, and $\pi_j = b$ for all $j \in \mathcal{N} \setminus \{i\}$ independent of s_i. For player i, the monetary payoff from choosing $s_i^0 = e_L$ is b, while deviating to other strategies never strictly increases this monetary payoff but possibly strictly decreases it to a (for example, deviating to WHL). Hence, $(s_i = L)_{i=1}^N$ is a Nash equilibrium.

If all other players choose WHH, then WHH is a best response because (1) choosing WHH yields $\pi_i = c$ and $\pi_j = c$ for all $j \in \mathcal{N} \setminus \{i\}$; (2) deviating to L yields $\pi_i = b < c$ (and $\pi_j = a$); (3) deviating to WLL or WHL yields $\pi_i = b < c$ (and $\pi_j = a$), and (4) deviating to WLH yields the same π_i and π_j as choosing WHH. Hence, $(s_i = WHH)_{i=1}^N$ is a Nash equilibrium. Following similar arguments, we can show that $(s_i = WLH)_{i=1}^N$ is a Nash equilibrium.

If all other players choose WHL, then WHL is a best response because (1) choosing WHL yields $\pi_i = b$ and $\pi_j = b$ for all $j \in \mathcal{N} \setminus \{i\}$; (2) deviating to L yields $\pi_i = b$ and $\pi_j = a < b$; (3) deviating to WHH or WLH yields $\pi_i = a < b$ (and $\pi_j = b$), and (4) deviating to WLL yields the same π_i and π_j as choosing WHL. Hence, $(s_i = WHL)_{i=1}^N$ is a Nash equilibrium. Following similar arguments, we can show that $(s_i = WLL)_{i=1}^N$ is a Nash equilibrium.

However, $s_i^{10} = e_H$ violates subgame perfection because, in the subgame starting at $t = 1$ after someone has already taken e_L (and, thus, $d = 0$, or the "low" message), deviating from e_H to e_L increases one's monetary payoff from a to b (without changing others' payoffs). $\square$

Proof of Proposition 4 As in the proof of Proposition 6, in the first round of elimination, we can eliminate any strategies that involve waiting and taking e_H after someone else has already chosen e_L (independent of the number of low choices). Then, the proofs of second-round and third-round elimination follow immediately from that of Proposition 6. $\square$

Proof of Proposition 5 In the games with full monitoring and binding high choice at $t = 0$, the symmetric strategy profiles surviving iterated weak dominance are: (1) all players choose e_H at $t = 0$; and (2) all players wait at $t = 0$ and choose e_H when all $N - 1$ other players chose e_H at $t = 0$ (and e_H or e_L otherwise).

First of all, if $m = N - 1$ players chose high at $t = 0$, it is strictly better off for a waited player to choose high. The result of SPNEs is obvious. Let us consider the simple case, with $N = 3$, to find all possible symmetric strategy profiles that are consistent with the iterated elimination of weakly dominated strategies. The result can be easily generalized to cases with $N > 3$.

For $N = 3$, let us write the strategy as H, $WLLL$, $WLLH$, $WLHL$, $WHLL$, $WHHL$, $WHLH$, $WLHH$ and $WHHH$. If the player waited, the first letter after "W" is for the case in which no one chose e_H at $t = 0$ ($m = 0$), and the second (third) letter is for the choice of action when $m = 1$ ($m = 2$).

In $t = 1$, it is strictly better to take high when $m = 2$. So, we can eliminate $WLLL$ (by $WLLH$), $WLHL$ (by $WLHH$), $WHHL$ (by $WHHH$) and $WHLL$ (by $WHLH$). The remaining ones are H, $WLLH$, $WHLH$, $WLHH$ and $WHHH$.

We will show that none of the other strategies can be eliminated in this round. Consider the case in which one player chooses $WLLH$, and the other chooses a mixed strategy $pH \oplus (1 - p)WLLH$ with $p \in (0, \frac{b-a}{c-a})$. As can be seen from the following table, in this case, $WLLH$ and $WLLL$ are the only two pure strategies that serve as the best responses.

Therefore, $WLLH$ can be weakly dominated only by a mixture of $WLLH$ and $WLLL$, which is not possible, since $WLLH$ weakly dominates $WLLL$. In this way, we show that $WLLH$ cannot be dominated by any other strategies.

Strategy	Payoff
H	$pc + (1-p)a$
$WLLH$ (or $WLLL$)	b
$WLHH$ (or $WLHL$)	$pa + (1-p)b$
$WHLH$ (or $WHLL$)	$pb + (1-p)a$
$WHHH$ (or $WHHL$)	a

Similarly, $WHLH$, together with $WHLL$, are the only best responding pure strategies to one player choosing $WHLH$ and the other player choosing $p \cdot H \oplus (1-p) \cdot WHLH$ with $p \in (0, \frac{c-a}{2c-a-b})$. $WLHH$, together with $WLHL$, are the only best responding pure strategies to one player choosing the mixed strategy $pH \oplus (1-p) \cdot WLLH$ with $p \in (0, \frac{b-a}{c-a})$ and the other choosing $WLHH$. $WHHH$, together with $WHHL$, are the only best responding pure strategies to one player choosing $WHHH$ and the other choosing a mixed strategy $p \cdot H \oplus (1-p) \cdot WHLH$ with $p \in (0, 1)$. Following the above logic, we can show that $WHLH$, $WLHH$, and $WHHH$ cannot be dominated. In addition, H is the unique best response to all other players choosing $WLHH$.

Thus, in the first round of elimination, we can eliminate any strategy that involves choosing L after seeing all others choosing H at $t = 1$, but we cannot eliminate any of the following strategies: H, $WLLH$, $WHLH$, $WLHH$ and $WHHH$.

After eliminating $WLLL$, $WLHL$, $WHLL$ and $WHHL$, by repeating the same arguments for why other strategies cannot be eliminated in the first round, we can show that each strategy that survives the first round of elimination is, in fact, a unique best response to some strategies taken by other players. Hence, none of them can be eliminated further.

To summarize, (1) all players choose e_H at $t = 0$; and (2) all players wait and choose e_H or e_L when $m = 0, 1$ but choose e_H when $m = 2$ are strategy profiles consistent with iterated weak dominance.

Subgame-Perfect Nash Equilibria The subgame-perfect equilibria take the following forms. All players choose e_H at $t = 0$. In all other cases, all players choose "wait" at $t = 0$, choose e_H if $N-1$ other players chose e_H at $t = 0$, and choose e_H or e_L if $2, ..., N-2$ other players chose e_H at $t = 0$. In one case, all players also choose e_H if 0 or 1 other player chose e_H at $t = 0$. In another case, all players choose e_L if 0 or 1 other player chose e_H at $t = 0$. In another case, all players choose e_H if 0 other player chose e_H at $t = 0$ and choose e_L if 1 other player chose e_H at $t = 0$.

It is easy to check that any of the following strategies—H, $WHHH$, $WLLH$ and $WHLH$ — can constitute a pure-strategy symmetric subgame-perfect equilibrium. To see why it is not such an equilibrium for each player to choose the strategy $WLHH$, let us consider the case in which the other two players choose $WLHH$. In that case, a player would choose H and receive a monetary payoff c rather than the strategy $WLHH$ and receive a monetary payoff of b. $\square$

Proof of Proposition 6

First round of elimination Consider player i and any strategy profile $s_{-i} = (s_j)_{j \in \mathcal{N} \setminus \{i\}}$. We want to show that WHL (WHH) is weakly dominated by WLL (WLH). If s_{-i} satisfies $\mathbf{1}(\{j \in \mathcal{N} \setminus \{i\} | s_j^0 = e_L\} = \emptyset) = 0$ - i.e., some other players choose low at $t = 0$, which means $d = 0$ ("low" message) independent of s_i - then $\pi_i(s_i = WLL, s_{-i}) = b > \pi_i(s_i = WHL, s_{-i}) = a$, whereas $\pi_j(s_i = WLL, s_{-i}) = \pi_j(s_i = WHL, s_{-i})$ for all $j \in \mathcal{N} \setminus \{i\}$. Otherwise, if s_{-i} satisfies $\mathbf{1}(\{j \in \mathcal{N} \setminus \{i\} | s_j^0 = e_L\} = \emptyset) = 1$, which means that $d = 1$ ("no low" message) independent of $s_i = WLL$ or $s_i = WHL$, then $\pi_i(s_i = WLL, s_{-i}) = \pi_i(s_i = WHL, s_{-i}) = b$ and $\pi_j(s_i = WLL, s_{-i}) = \pi_j(s_i = WHL, s_{-i})$ for all $j \in \mathcal{N} \setminus \{i\}$. Hence, WHL is weakly dominated by WLL. The same argument can be applied to show that WHH is weakly dominated by WLH.

To see why WLH, WLL and L cannot be eliminated in this round, consider any mixed strategy that might dominate any of these three strategies. If such a mixed strategy exists, and if it assigns positive probabilities to WHH and/or WHL, then we can rearrange those probabilities to WLH and/or WLL, respectively, to get another weakly dominant strategy (since WHH and WHL are weakly dominated by WLH and WLL). So, we need only consider a mixed strategy consisting of WLH, WLL and L as possible ones that weakly dominate any of the three strategies.

First, note that any mixed strategy consisting of L and WLL cannot dominate WLH because WLH is the best response to $s_{-i} = (s_j = WLH)_{j \in \mathcal{N} \setminus \{i\}}$.

Now, suppose that L can be weakly dominated by $s^0 = p \cdot WLL \oplus (1-p) \cdot WLH$ for some $p \in [0, 1]$. Consider the case in which $s_{-i} = (s_j = WLL)_{j \in \mathcal{N} \setminus \{i\}}$. Then, $\pi_i(s_i =$

$L, s_{-i}) = b$, $\pi_i(s_i = s^0, s_{-i}) = pb+(1-p)a$, while $\pi_j(s_i = L, s_{-i}) = \pi_j(s_i = s^0, s_{-i}) = b$. So, the weak dominance implies that $p = 1$, and $s^0 = WLL$. Consider the other case, in which $s'_{-i} = (s_j = WLH)_{j\in\mathcal{N}\setminus\{i\}}$. Then, $\pi_i(s_i = L, s'_{-i}) = \pi_i(s_i = s^0, s'_{-i}) = b$, while $\pi_j(s_i = L, s'_{-i}) = b > \pi_j(s_i = s^0, s'_{-i}) = a$, which means that L is preferred to s^0. Therefore, no such $p \in [0, 1]$ exists for the weak dominance. Hence, L cannot be weakly dominated by any possible mixed strategy. Similarly, we can prove that WLL cannot be weakly dominated by any mixed strategy.

Second round of elimination The remaining strategies are L, WLL and WLH. For player i, given any strategies chosen by others that s_{-i}, $\pi_i(s_i = WLL, s_{-i}) = \pi_i(s_i = L, s_{-i}) = b$. If some other players choose L , which means that $d = 0$ regardless of s_i, then $\pi_j(s_i = L, s_{-i}) = \pi_j(s_i = WLL, s_{-i})$ for all $j \in \mathcal{N} \setminus \{i\}$. That means that player i is indifferent between L and WLL. The indifference also holds when $s_j = WLL$ for all j. However, if, among other players, no one chooses L and some players choose WLH - i.e., $|S^{WLH}_{-i}| \geq 1$ ($S^{WLH}_{-i} \equiv \{j|s_j = WLH\}$) - then $\pi_{j'}(s_i = L, s_{-i}) = b > \pi_{j'}(s_i = WLL, s_{-i}) = a$ for all $j' \in S^{WLH}_{-i}$, and $\pi_j(s_i = L, s_{-i}) = \pi_j(s_i = WLL, s_{-i}) = b$ for all $j \in (\mathcal{N} \setminus \{i\}) \setminus S^{WLH}_{-i}$. Hence, under the considerate social preference assumption, WLL is weakly dominated by L.

No other strategies can be eliminated in this round. WLH is the unique best response if all others take WLH. When all others choose WLL, compared with strategy WLH, choosing L yields a strictly higher payoff to player i but the same payoffs to other players. Therefore, L cannot be dominated by WLH. Since we have already shown that L weakly dominates WLL, L cannot be eliminated in this round.

Third round of elimination The remaining strategies are L and WLH. Consider any strategy profile s_{-i} chosen by other players. If someone chooses L, which means that $d = 0$, then player i is indifferent between L and WLH. Otherwise, if no one chooses L in s_{-i}, then $\pi_i(s_i = WLH, s_{-i}) = c > \pi_i(s_i = L, s_{-i}) = b$, and $\pi_j(s_i = WLH, s_{-i}) = c > \pi_j(s_i = L, s_{-i}) = b$ for all $j \in \mathcal{N} \setminus \{i\}$. Hence, L is weakly dominated by WLH. $\square$