Real-time Monitoring in a Public-Goods Game*

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Abstract

We investigate a novel continuous-time mechanism in a public-goods game. In this game, a clock ensures that contributions increase in equal speed within a fixed period for each player. The players can choose when to stop their contributions from increasing, while their actions are observed by others in real time. We demonstrate, both theoretically and experimentally, that the mechanism is effective in improving contributions. Three critical factors could play a role in this improvement: announcements, incremental commitments, and the clock. We further decompose these factors and find that while announcements alone are not effective, adding incremental commitments and using the clock are both significant in improving contributions.

Keywords: Public goods, continuous time, incremental commitments, announcements.

JEL codes: C72, C92, D82.

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1 Introduction

Public goods games are very prevalent in economics, and their desired outcomes require people to contribute efficiently towards the public good. For example, fighting global warming problem requires all countries to reduce their carbon emissions. However, the problem is challenging because non-contributions to the public good are in people's private interests, which is supported by the Nash equilibrium. Many experimental studies confirm that contributions to the public good tend to converge to a low level once people gain experience with playing the game.[1] However, many studies find effective mechanisms that can improve contributions to the public goods.[2] These mechanisms may involve punishment or reward institutions, endogenous sorting partners, or pre-game communications, etc.[3]

In this study, we introduce a novel continuous-time mechanism in a four-player linear public goods game. The mechanism works as follows: within one minute, the contribution of each player is monotonically increased over time by an exogenously imposed clock, and players can choose when to stop their contribution from increasing. Whenever a player stops, others can observe this in real time.[4] Each player's decision to stop is irreversible, and it determines one's contribution to the public good; the earlier one stops, the less one contributes. To the best of our knowledge, this is the first study to implement such a mechanism within cooperative environments.[5]

Such a mechanism is worth investigating for both theoretical and empirical reasons. Theoretically, this setup enables players who are conditional cooperators to contribute only if others contribute. Moreover, in a continuous-time environment, players may become tolerant of earning slightly less than others earn by choosing to stop only after observing others' stop, which is consistent with the intuition of ϵ-equilibrium (Radner, 1986; Simon and Stinchcombe, 1989; Bergin and MacLeod, 1993). Therefore, this mechanism could potentially induce a significant contribution. There are many economic situations in which the mechanism can be implemented. For example, if community members wish to

[1] See Andreoni (1988), Isaac and Walker (1988a), and Isaac and Walker (1988b), among others.

[2] There are many underlying reasons for why people can reach a high contribution in public goods games, including kindness, conditional cooperation, etc.; see Andreoni (1995), Fischbacher et al. (2001), and Fischbacher and Gächter (2010), among others.

[3] See Chaudhuri (2011) for a survey.

[4] This phase is similar to the Dutch auction but in reverse, in that there is a clock, and each person can choose when to stop increasing (or decreasing) one's own contribution (or bidding price).

[5] Calford and Oprea (2017) study a similar mechanism, but in a competitive game with fewer number of players. We will discuss their study in greater detail in Section 2.

improve their public facilities, they can introduce a program where they slowly increase each member's contribution daily, and the members can opt out whenever they like. During the process, they can observe how many people choose to opt out or stay in the program.

We call our main mechanism *Incremental Commitment with a Clock*. In this mechanism, many factors may improve the contribution. To understand the factors that are critical in inducing contribution, we break down the main mechanism into another four setups. We start by including the game without any mechanisms as a *Baseline* setup. The first mechanism is *Announcement*, in which players have one minute to send announcements freely, and the announcements are perfectly observed by the group. After this minute, players can choose to make nonbinding contributions. The second mechanism is *Final Commitment*. This mechanism adds the "final commitment" to the *Announcement*, such that players' last announcements become their actual contribution within the game. The next mechanism, *Incremental Commitment*, imposes an irreversible commitment, in which players can only increase their announced contributions in comparison to their own previous announcements during the one-minute interval. Finally, in our main mechanism, we add a "clock", which contains pre-set speeds that are equal for each player.

Theoretically, the Nash equilibrium predictions are the same for all the five setups. That is, players contribute zero to the public good. However, because the decisions are sequential, and the decision time is continuous in the *Incremental Commitment with a Clock*, we apply the subgame perfect ϵ-equilibrium to make the theoretical predictions for this mechanism. We find that, with standard preferences, there exist the subgame perfect ϵ-equilibria, in which one player stops contributing at the very beginning of the timeframe, but the other three players have a near-dominant strategy to continue contributing unless a second player stops. Furthermore, when players are sufficiently inequality averse, it is a near-dominant strategy for each player to keep contributing unless one player stops; that is, in the subgame perfect ϵ-equilibria, everyone may contribute fully to the public good.[6] The intuition of such near-dominant strategies is that, by continuing to contribute when there are sufficient number of players that stay, the total return rate is determined by the joint contribution of those players; however, if one opts out, they anticipate that the remaining players will immediately follow, resulting in a cooperation breakdown and a lower return rate. In summary, the subgame perfect ϵ-equilibrium predicts that it is possible to sustain high contribution levels in our main mechanism, especially when

[6]See Fehr and Schmidt (1999), who first introduce inequality aversion in the economic literature.

players are inequality averse. However, there are many other equilibria in which players fail to contribute as much. Therefore, it remains an empirical question of which equilibria will be selected.

We bring all the setups to the laboratory as five between-subject treatments. In all treatments, subjects are assigned to a fixed matching group of eight, who are randomly divided into two groups of four players to play the public goods game. They play the same game for 20 rounds, and in each round, are randomly re-matched within their matching group. Arguably, it is more difficult to achieve a high contribution level under random matching, compared to fixed matching.[7] This design allows us to avoid individual reputation effects, and to make the game more comparable to a one-shot game.

The experimental results show that in treatments *Baseline*, *Announcement*, and *Final Commitment*, contributions converge to zero over time. Although subjects tend to announce a high-intended contribution in the latter two treatments, they deviate to a much lower level at the end of the game. In treatment *Incremental Commitment*, contributions do not decay over time, and remain at around 45% of the maximal level. Finally, in treatment *Incremental Commitment with a Clock*, although contribution levels do not differ from the other treatments at the beginning, they increase over time and reach approximately 75% of the maximal level during the last few rounds. We further find that the behavioral patterns are largely consistent with the predictions of the ϵ-equilibrium with sufficiently strong linear inequality aversion. The data suggest that subjects often use the near-dominant strategy, in which they keep contributing until one of the players stops. These experimental results are not trivial because there are many other equilibria in which subjects fail to use the near-dominant strategies and contribute significantly less, suggesting that our main mechanism and its underlying near-dominant strategy are behaviorally obvious for the subjects. In summary, our experimental findings indicate that, under real-time monitoring, using announcements alone, with or without final commitment, are not sufficient to boost contributions. In contrast, both incremental commitments and using the clock are very effective in improving contributions.

The remainder of this paper is organized as follows. Section 2 discusses related literature. Section 3 presents theoretical predictions. Section 4 introduces the experimental

[7]For example, Fehr and Gächter (2000) find that punishment options increase contributions in both partner matching and stranger matching, but the contributions reach a higher level under partner matching. Walker and Halloran (2004) find that under random matching, neither rewards nor sanctions have any significant impact on contributions, suggesting that repeated interactions and the consequent dynamics play an important role in sustaining cooperation with punishments.

design and procedures. Section 5 presents the experimental results. Section 6 concludes.

2 Related literature

An emerging number of experimental studies have explored games with continuous time interactions. In these studies, players usually play games within a fixed time intervals, during which they can change their actions at any time, and their actions can be observed by other players in real time. Depending on how payoffs are determined, these studies can be divided into two types. In the first, payoffs are usually determined by the actions at the last instant of the game. In the second, payoffs accumulate over time. Such games are often referred to as "continuous games." In this study, we explore multiple continuous-time mechanisms of the first type in the public-goods game.

Among the the first type of continuous-time studies, our main mechanism is predominantly related to Calford and Oprea (2017). They study a simple timing game, similar to the one in Simon and Stinchcombe (1989), both under discrete time and continuous time interactions. In this game, two agents independently decide when to enter a market, and joint delay is beneficial for both agents. In perfectly discrete time, agents will enter the market at the very beginning of the game in equilibrium, yielding an inefficient outcome. In perfectly continuous time, agents can achieve maximal joint profits in equilibrium by jointly delaying entry. In their experiments, they compare behaviors under perfectly discrete time, perfectly continuous time, and non-perfectly continuous time with exogenously imposed "reaction lags." They find that when the reaction lag is sufficiently small, subjects behave more as if they would in a perfectly continuous time environment; that is, they delay entry and achieve almost the maximal profits. The continuous time game of our main mechanism shares this similarity with the timing game under non-perfectly continuous time. By applying the ϵ-equilibrium, high contributions can potentially be supported theoretically, as long as players can forgo a payoff loss that is determined by their reaction time. In contrast to Calford and Oprea (2017), the reaction lags in our game are endogenously determined by the players' natural reaction time and technical constraints. Therefore, in our study, whether high contributions can be achieved is an empirical question. Moreover, compared to the two-player entry game featuring competition in Calford and Oprea (2017), our public goods game features a cooperative environment with four players, making high contributions potentially more challenging.

Next, we are directly related to the first type of studies on public-good games. Dorsey

(1992) first introduces real-time monitoring in public-goods games. In three-minute stages, subjects are allowed to increase only their contribution level, and their actions are perfectly monitored by others. He finds that such an irreversible mechanism could prevent rapid decay, whereas a reversible condition fails to do so. Kurzban et al. (2001) replicate Dorsey's (1992) design and study the effects of different informational disclosures. They find that only the combination of providing the lowest contribution and the irreversible setting could eliminate the decay trend. Later, Tan et al. (2015) find that the irreversible mechanism in Dorsey (1992) is only effective among inexperienced subjects. Cason and Zubrickas (2019) also study this real-time setting with irreversible contributions, but with a focus on refund bonuses. They find that the refund bonus policy is more effective in real-time setting than static ones.[8] Our *Incremental Commitment* mechanism is similar to this because players can only increase their contribution level over time. However, we only introduce such a mechanism to break down the effect of a few factors in our main mechanism.

A few continuous-time studies have focused on minimum-effort games. In the experiment of Deck and Nikiforakis (2012), subjects can choose their actions and change them freely at any time in a one-minute pre-game phase. These actions can be perfectly or imperfectly observed by the other group members. They find that when subjects could perfectly monitor the choices of all other group members, efficient coordination could be achieved. Our *Final Commitment* mechanism is similar to their perfect monitoring setting. Avoyan and Ramos (2020) study the effect of pre-game real-time interaction in a minimum-effort game. In their main treatment, subjects are allowed to revise their actions with an exogenously determined probability, and their last-instant actions are binding. They find that such a mechanism enables subjects to communicate their actions with incremental commitments, which is successful in inducing the Pareto optimal equilibrium. Our main setup, *Incremental commitment with a clock*, also allows players to communicate their actions with incremental commitments. In addition, we use a clock that allows an equally increasing pace in the commitment level. We introduce this stronger mechanism because, compared to minimum effort games, it is arguably more difficult to achieve a socially desirable outcome in public-goods games, as it is not supported by the Nash equilibrium. To identify the essential factors behind the mechanism, Avoyan and Ramos (2020) further test some other mechanisms. For the first mechanism, they remove the

[8] There are some parallel experimental studies that employ discrete time interactions in dynamic public goods games (Duffy et al., 2007; Choi et al., 2008). They find that subjects contribute more in a dynamic game than a static one.

commitment feature from the main mechanism by making the last action nonbinding. Our *Announcement* mechanism is similar to this, and we achieve similar results, which is that such a mechanism is ineffective. Second, they introduce an infrequent-revision mechanism, in which players are not given sufficient revision opportunities to maintain coordination, as suggested by theory. This mechanism is found to be ineffective in this experiment. Our *Incremental Commitment* setup serves a similar role because compared to our main mechanism, this setup removes the equal pace of incremental commitments; thus, it turns out to be less effective than our main mechanism. Overall, our results share a similar spirit with Avoyan and Ramos (2020); that is, to achieve a high contribution in public goods games, it is essential to maintain gradual commitments with an equal pace among the players.

For the second type of continuous games, Friedman and Oprea (2012) first study a two-person continuous-time prisoner dilemma game, in which players receive flow payoff that accumulate over a one-minute interval. The subjects reach a high cooperation rate in this setting. Oprea et al. (2014) extend the same payoff structure to a public goods game with a 10-min payoff accumulation stage. They find that the effect of a continuous game from a prisoner dilemma is muted in a public goods game. However, when adding communication in a continuous game setting, the subjects contribute significantly more.[9]

Finally, many studies find that pre-game communication, especially free-format communication and face-to-face communication, can improve the contribution of public goods games (Isaac and Walker, 1988a; Wilson and Sell, 1997; Bochet et al., 2006; Denant-Boemont et al., 2011).[10] Our *Announcement* treatment is especially relevant to Bochet et al. (2006) and Denant-Boemont et al. (2011). We differ from them in that our design allows subjects to make announcements as many times as they want to in the pre-game stage.

3 Theoretical predictions

In this section, we make theoretical predictions for each mechanism in a four-player linear public goods game. In the normal-form public goods game G, each player chooses their

[9]See more experimental work on continuous games in Bigoni et al. (2015) and Leng et al. (2018), among others.

[10]Other mechanisms are also found to be effective in improving contributions in public goods games. For example, punishment and reward (Fehr and Gächter, 2000; Masclet et al., 2003; Walker and Halloran, 2004; Gunnthorsdottir et al., 2007; Nikiforakis, 2008; Yang et al., 2018), endogenously formed groups (Gächter and Thöni, 2005; Gunnthorsdottir et al., 2007; Charness and Yang, 2014), etc.

contribution level $g_i \in [0, 20]$, and their payoffs are described in the function below.

$$\pi_i = 20 - g_i + 0.4 \sum_{j=1}^{4} g_j \tag{1}$$

3.1 Nash equilibrium predictions

3.1.1 Baseline

In the *Baseline* setup, each player chooses a contribution level $g_i \in [0, 20]$ simultaneously in the normal-form game G. It is a dominant strategy to choose $g_i = 0$. Therefore, there is a unique Nash equilibrium where all players choose a zero contribution.

3.1.2 Announcement

In the *Announcement* setup and after the one-minute announcement phase, each player chooses a contribution level $g_i \in [0, 20]$ simultaneously in the normal-form game G.[11] Regardless of what they say in the announcements phase, it is still a dominant strategy to choose $g_i = 0$. Therefore, the Nash equilibrium is the same as that of the *Baseline*.

3.1.3 Final commitment

In the one-min phase of the *Final Commitment* setup, the last announcement made by each player is payoff-relevant and becomes their actual contribution in the game, and all the previous announcements of each player, if there are any, are payoff-irrelevant.

In this dynamic game G^{FC}, at any time within the one-minute interval, players can choose whether to make an announcement $m_{it} \in [0, 20]$. The player's strategy can depend on the time t and the announcements previously made by the other three players by time t. Therefore, the strategy space becomes significantly large. Let τ denote the homogeneous reaction time of players (with $0 < \tau \ll 1$); we argue that, no matter what announcements are sent by the four players during $t \in [0, 1 - \tau)$, it is a dominant strategy to send zero contributions when $t \in [1 - \tau, 1]$.[12] Thus, $m_{it} \in [0, 20]$ if $t \in [0, 1 - \tau)$, $m_{it} = 0$ if $t \in [1 - \tau, 1]$. This is because when a player makes an announcement of zero contributions at the end of

[11] Since the announcement phase does not impose any restrictions on the actual contribution choices, such a setup can also be referred to as "cheap talk" (Farrell and Rabin, 1996; Crawford, 1998).

[12] The reaction time τ denotes the minimal time it takes a player to react after seeing a change in others' announcements in the continuous time interactions. For simplicity, this study assumes that all players share the homogeneous reaction time τ.

the one-minute interval, other players do not have sufficient time to adjust their actions accordingly. As explained, regardless of the contribution level of the other three players, it is a dominant strategy to contribute zero. Therefore, there is a unique Nash equilibrium outcome, in which each player contributes zero to the public good.

3.1.4 Incremental commitment

In the *Incremental Commitment* setup, players choose their contributions in the one-minute phase, and their updated contribution level can only be higher than the previous contribution level; the actual contribution is determined by the last update.

In this continuous-time dynamic game G^{IC}, the strategy of each player depends on the time $t \in [0,1]$ and all the previous actions. Despite this large strategy space, we argue that any outcome with a positive total contribution level cannot be a Nash equilibrium outcome. If we consider an outcome with a positive total contribution, there must be a player who is last (or one of the last ones) to increase his contribution in the one-minute interval. For such a player, since no one increases their contribution after he does, he can earn a profit by not making the last update. Therefore, there is a unique Nash equilibrium outcome where each player contributes zero to the public good.

3.1.5 Incremental commitment with a clock

In the *Incremental Commitment with a Clock* setup, an exogenous clock increases the contribution within a one-min interval, and the increasing pace is identical for all players. Hence, from $t = 0$ to $t = 1$, the contribution of each player is increased from 0 to a full contribution of 20, at a speed of 20 per minute (or $\frac{1}{3}$ per second). At any time during this interval, each player can choose when to opt out from increasing their contribution. Once a player opts out, his contribution is finalized at that time: if a player opts out at time $t \leq 1$, his contribution level is uniquely determined as $20t$. A player's opting out decision can be observed by all the other players in real time, with a reaction time τ ($0 < \tau \ll 1$).

In this continuous-time dynamic game G^{ICC}, at any given time $t \in [0,1]$, the history is denoted as $h(t) = \{t_1, t_2, t_3, t_4\}$, with $t_j \leq t$. Such a history $h(t)$ contains the time length that each player stays in the game for the period in $[0,t]$. For example, t_1 denotes how much time player 1 stays in the game by time t: if $t_1 = t$, it means that player 1 remains in the game at time t, and if $t_1 < t$, then player 1 has already opted out. The strategy space of each player should contain the history of all the players. Note that, for any player i, if by time t he has already opted out ($t_i < t$), then his contribution level is finalized and he no longer needs to take any further actions; in other words, he must choose to opt out in the remaining game after t_i. Therefore, we arrive at the following mapping rules from game history to strategies: Let $H(t) = \cup_{t=0}^{1} h(t)$ denote the union of all the possible histories for the entire time period. Each player i has this strategy $\sigma_i : H_i(t) \rightarrow \{Stay\ in,\ Opt\ out\}$, s.t. $\forall h_i(t) = \{t_1, ...t_4\}$ with $t_i < t$, $\sigma_i : h_i(t) \rightarrow \{Opt\ out\}$.

In this dynamic game G^{ICC}, we demonstrate once again that there is a unique Nash equilibrium outcome, in which each player opts at $t = 0$. Consider an outcome in which player i is the last one to opt out ($t_i \geq t_j, \forall j$=1,2,3,4) and $t_i > 0$. For such a player i, he is better off by choosing to stop a bit earlier at $t_i - \sigma$, with $\sigma \leq \tau$. Such a deviation can increase player i's payoff by 20σ, while not making other players change their actions. Therefore, any outcome with $t_j > 0$ for an arbitrary player j cannot survive as a Nash equilibrium. The only Nash equilibrium outcome is the one in which everyone contributes zero to the public good. In other words, they all opt out at $t = 0$.

Proposition 1 (Nash equilibrium). *In all setups, there is a unique Nash equilibrium outcome, in which all players contribute zero to the public good.*

3.2 ϵ-equilibrium predictions with standard preferences

One critical feature of *Incremental Commitment with a Clock* is that players observe each other's actions in real time (with a time lag τ) and can adjust their strategies accordingly. For example, if player i opts out immediately after observing that player j just opts out, player i's payoff is slightly lower than player j, given that τ is quite small. Therefore, it is reasonable to apply the ϵ−equilibrium in this game. Below, we provide three definitions that are useful for understanding the theoretical analysis in this section.

Definition 1 (ϵ-best response). *Given the strategy profile P_{-i} of the other players, suppose that for player i, strategy s^* yields the highest payoff, then all the strategies $\tilde{s}$ such that $u(s^*) - u(\tilde{s}) \leq \epsilon$ belong to the ϵ-**best responses** strategy set $B_{i,\epsilon}(P_{-i})$.*

Definition 2 (ϵ-equilibrium). *A strategy profile P^* is an ϵ-**equilibrium** if for any player i, his strategy in P^* belongs to his ϵ-best response set $B_{i,\epsilon}(P^*_{-i})$.*

Definition 3 (near-dominant strategy). *For player i, given any strategy profile P_{-i} of the other players and the value of ϵ, if strategy $\tilde{s}_i$ always belongs to $B_{i,\epsilon}(P_{-i})$, then $\tilde{s}_i$ is a near-dominant strategy for player i.*

The intuition to apply ϵ-equilibrium in this continuous time setup is that, more equilibria can arise if players can forgo a small amount of payoff loss ϵ, by conditioning their strategies on the opting out actions of the other players. We denote the number of players who have already opted out at time t as n_t and the opting time of the n^{th} player who opts out as o_n. We solve the subgame perfect ϵ-equilibria by using the following procedure:

(i) First, consider that $n_t > 1$. For the remaining player(s) in the contributing phase, the return rate is no greater than 0.8×20 per min if they choose to "stay in," which is strictly less than the return rate of 1×20 per min if they "opt out." This indicates that for any opting time o_2 of the second quitter(s), the best response for the remaining player(s) in the subgame is to opt out as soon as possible.

(ii) Consider $n_t = 1$. From (i), we know that for any player who has not opted out (i.e., player 2), if player 2 opts out at o_2 (and he opts out earlier than the other two remaining players), the two remaining players will opt out as soon as they can (at $min\{o_2 + \tau, 1\}$). Therefore, the payoff of player 2 by opting out at o_2 is as follows:

$$\pi_{secondquitter}(o_2) = \begin{cases} 8o_1 + 4o_2 + 16\tau & 0 \leq o_2 \leq 1 - \tau \\ 8o_1 - 12o_2 + 16 & 1 - \tau < o_2 \leq 1 \end{cases} \tag{2}$$

The above equation shows that player 2's payoff increases in o_2 when $0 \leq o_2 \leq 1 - \tau$, and decreases in o_2 when $1 - \tau < o_2 \leq 1$. Therefore, the optimal strategy for player 2 is to stay until $t = 1 - \tau$, provided that he opts out earlier than the other two players.

However, player 2 may have an incentive to opt out before $t = 1 - \tau$ if he worries that another player j will opt out before $t = 1 - \tau$ (player j is one of the remaining players when $n_t = 1$). Consider that, if another player j opts out at $\tilde{t} < 1 - \tau$, the best response for player 2 is to opt out at $\tilde{t} - \tau$, whereas if he uses the strategy to leave at $1 - \tau$ when $n_t = 1$, he will opt out at $min\{\tilde{t} + \tau, 1 - \tau\}$. The maximum loss compared to the best response is 24τ (see the detailed proofs in Appendix A). In summary, when $n_t = 1$, a strategy to "opt out if $t \geq 1 - \tau$ or $n_t > 1$" can guarantee that one forgoes 24τ at most, compared to the best response, regardless of the strategy of others. According to Definition 3, for $\epsilon \geq 24\tau$, such a strategy is a near-dominant strategy for each of the three remaining players when $n_t = 1$. As for the scale of 24τ, it naturally depends on the reaction time τ; if it takes players 1 second ($\tau = \frac{1}{60}$) to react, then $24\tau = 0.4$. Hence, with a reaction time of 1 second, the strategy above is a near-dominant strategy if players can forgo a payoff loss that is no less than 0.4, which accounts for only 2% of the payoff if a player contributes zero to the public good.

(iii) Finally, consider $n_t = 0$. From (ii), we know that the remaining three players have near-dominant strategies that are independent of o_1. By backward induction, the best response for the first quitter is to opt out at $t = 0$. We define the following "cutoff strategy" and derive subgame perfect ϵ-equilibria with the near-dominant strategies.

Definition 4 (cutoff strategy)**.** *The cutoff strategy $k(s_1, s_2, q)$ in game G^{ICC} specifies the conditional cutoff time s_1, s_2, the trigger number q, which is to "opt out" if (i) $n_t < q$ and $t \geq s_1$ or (ii) $n_t = q$ and $t \geq s_2$, or (iii) $n_t > q$, and "stay in" otherwise.*

Proposition 2 (Subgame perfect ϵ-equilibria with near-dominant strategies)**.** *In G^{ICC}, if $\epsilon \geq 24\tau$, there exist subgame perfect ϵ-equilibria in which one player has strategy $k(0, s, 1)$, and the other three players use a near-dominant strategy $k(s, s, 1)$ with $s \in [1 - \tau - \frac{\epsilon}{4}, 1]$.*[13]

We previously show that if $\epsilon \geq 24\tau$, $k(1 - \tau, 1 - \tau, 1)$ is a near-dominant strategy in the subgame when exactly one player has opted out. However, given the exact value of ϵ, there will be more near-dominant strategies in this subgame, and their cutoff time can be slightly earlier or later than $1 - \tau$. Detailed proofs are provided in Appendix A.

First, note that there are more subgame perfect ϵ-equilibria in which all players use near-dominant strategies, but their conditional cutoff time s is slightly different. This is because, given the definition of ϵ-equilibrium, there are always many best response strategies that share close conditional cutoff times, given others' strategies.

Furthermore, note that there is another type of subgame perfect ϵ-equilibria in which players do not use near-dominant strategies. Instead, one player opts out at the very beginning of the game and the other three players use cutoff strategies $k(s, s, 1)$, in which their conditional cutoff time s falls outside of $[1 - \tau - \frac{\epsilon}{4}, 1]$ but are close to one another. In other words, the three other players "happen to" opt out at a very similar time. However, such equilibria are arguably harder to achieve because they require players to coordinate the time at which they opt out. Compared to the equilibria in Proposition 2, subjects in such equilibria may leave much earlier and hence contribute less.

Overall, for simplicity, in this study we focus on the equilibria with near-dominant strategies and identical conditional cutoff times across players.

[13]The second parameter in strategy $k(0, s, 1)$ and the first parameter in strategy $k(s, s, 1)$ denote off-equilibrium-path strategies. In Appendix A, we discuss why these strategies best respond to each other.

3.3 ϵ-equilibrium predictions with linear inequality aversion

In the above theoretical analysis, we assume that players have standard preferences; they care only for their own monetary payoffs. In the equilibria characterized in Proposition 2, there is a strong asymmetry between the player who opts out unconditionally at $t = 0$ and the other three players who opt out by the end of the one-min interval. In such equilibria, one player free-rides on the other three players. Current empirical evidence on inequality aversion suggests that it can be challenging for such asymmetric equilibria to occur: when the remaining three players in the subgame are sufficiently inequality averse, it is possible that they would opt out as soon as the first player opts out, to reach a fairer result, even by sacrificing their monetary payoffs.

In this section, we examine how our theoretical predictions change if players are inequality averse. We adopt the utility function from Fehr and Schmidt (1999), as follows: We assume that all players have a homogeneous inequality-averse level $\alpha \geq 0$, which captures how they dislike if others receiver a higher monetary payoff than they do.[14] [15]

$$U_i(x) = 20x_i - \alpha \sum_{j \neq i} \frac{1}{n-1} \max\{x_j - x_i, 0\} \tag{3}$$

We solve the subgame perfect ϵ-equilibria by the following procedure:

(i) First, consider that $n_t > 1$. For the remaining player(s) in the subgame, introducing inequality aversion lowers their return rate if they choose to "stay in," compared to the standard preference case, while it doesn't affect the return rate if they choose to "opt out." This indicates that for any o_2 of the second quitter(s), the best response for the remaining player(s) is still to opt out as soon as they can.

(ii) Consider $n_t = 1$. When the remaining three players in the subgame stay, and although staying in increases their monetary payoffs effectively, it also enlarges the payoff difference between them and the first quitter. The return rate of the former is $20 \times 0.4 \times 3$ per minute; the payoff difference rate is 20 per minute, because the free rider enjoys the same benefit of the public good, but he can also receive extra payoffs from his own private

[14] Note that in Fehr and Schmidt (1999), they also consider the dis-utility if one receives a higher monetary payoff than others do. However, in our analysis, we simplify the utility function and only consider the dis-utility when one receives a lower monetary payoff than others do. We further simplify the parameter α to be homogeneous among players. By imposing these two assumptions, we can abstract away from the other possible variations and derive the essential intuition.

[15] Note that Fehr and Schmidt (1999) is a linear form of inequality aversion. We extend our analysis to the non-linear form in Appendix B.

account. The sum of the gain of staying in is presented in the following equation:

$$\frac{\partial U_i(x)}{\partial t} = 20 * 0.4 * 3 - \alpha * \frac{1}{3} * 20 \tag{4}$$

If one chooses to opt out instead, he will contribute his endowment to his private account at a return rate of 1. Because the other two players will follow him and opt out, the total return rate is still 1. This is presented in the following equation:

$$\frac{\partial U_i(x)}{\partial t} = 20 * 1 \tag{5}$$

The equilibria in Proposition 2 will break down when staying in (equation (4)) has a strictly lower value than opting out (equation (5)), which yields the following condition:

$$\alpha > 0.6 \tag{6}$$

This condition means that if players are sufficiently inequality-averse ($\alpha > 0.6$), when one player opts out from the contributing phase, the remaining three players will opt out as soon as possible.

(iii) Back to $n_t = 0$, given (ii), *for* $\alpha > 0.6$, then if a player wishes to opt out first at o_1, her payoff will be as follows:

$$\pi_{firstquitter}(o_1) = \begin{cases} 12o_1 + 24\tau + 20 & 0 \leq o_1 \leq 1 - \tau \\ 44 - 12o_1 & 1 - \tau < o_1 \leq 1 \end{cases} \tag{7}$$

The above equation shows that, for the first player who chooses to opt out, the optimal opting out time is $t = 1 - \tau$, provided that he opts our earlier than all the other three players do.

However, the first quitter may have an incentive to opt out before $t = 1 - \tau$ if he worries that another player j will opt out before $t = 1 - \tau$. Consider that another player's strategy is $k(\cdot, \tilde{t}, 0)$ with $\tilde{t} < 1 - \tau$, the best response for the first quitter is $k(\cdot, \tilde{t} - \tau, 0)$, whereas using the strategy $k(\cdot, 1 - \tau, 0)$ means that one only opts out at $min\{\tilde{t} + \tau, 1 - \tau\}$.[16] The maximum loss of using the strategy $k(\cdot, 1 - \tau, 0)$ is $(24 + 20\alpha)\tau$ (see detailed proofs in Appendix A). Hence, when $n_t = 0$, according to Definition 3, for $\epsilon \geq (24 + 20\alpha)\tau$, the cutoff strategy $k(\cdot, 1 - \tau, 0)$ is a near-dominant strategy for all the four players. Furthermore, the scale of $(24 + 20\alpha)\tau$ depends on the reaction time τ and the inequality aversion level α: suppose that $\tau = \frac{1}{60}$

[16] In a cutoff strategy with $q = 0$, it is not possible to have $n_t < q$; therefore, the first parameter s_1 is undefined.

and $\alpha = \frac{4}{5}$, then $(24+20\alpha)\tau = \frac{2}{3}$. Thus, the above strategy is near-dominant if players can forgo a payoff loss equal to or greater than $\frac{2}{3}$.

Proposition 3 (Subgame perfect ϵ-equilibrium with near-dominant strategies under linear inequality aversion)**.** *In G^{ICC}, if players are sufficiently inequality averse in the linear inequality-averse form ($\alpha > 0.6$) and for $\epsilon \geq (24+20\alpha)\tau$, there exist subgame perfect ϵ-equilibria in which all players use a near-dominant strategy $k(\cdot, s, 0)$ with $s \in [1-\tau-\frac{\epsilon}{12}, 1]$.*

We previously show that if $\epsilon \geq (24+20\alpha)\tau$, $k(\cdot, 1-\tau, 0)$ is a near-dominant strategy for each player. However, given the exact value of ϵ, there are more near-dominant strategies, and their cutoff times can be slightly earlier or later than $1-\tau$. Detailed proofs are provided in Appendix A.

As with the predictions under standard preferences, there are also more subgame perfect ϵ-equilibria with inequality-aversion. In the other equilibria, all players can opt out much earlier if their opting-out times are close to one another. Note that, compared to Proposition 3, subjects in the other equilibria may contribute much less. Again, we focus only on the equilibria with near-dominant strategies and identical cutoff times across players, because we consider them behaviorally obvious and easier to achieve.

4 Experimental design and procedures

4.1 Treatment design

In the experiment, we employ a between-subject design to implement the five setups described in Section 3.1. The treatments are *B (Baseline)*, A (Announcement), *FC (Final Commitment)*, *IC (Incremental Commitment)*, and *ICC (Incremental Commitment with a Clock)*.

Each subject participates in only one treatment. In the experiment, all subjects play the same public good game for 20 rounds.[17] They choose their contribution as any number from 0 to 20. To make the experimental results more comparable to the theoretical predictions of the one-shot game, we adopt a random matching protocol for all treatments. The subjects are randomly assigned to a fixed matching group of eight. In each of the 20 rounds, the 8 subjects within a matching group are randomly divided into two 4-player groups to participate in the experimental game. Thus, subjects cannot form long-term

[17] The game is described by Equation 1 in Section 3.

partnerships or build a reputation in their matching group because they cannot identify one another.

The design of the five treatments closely follow the theoretical setup. Compared to treatment *B*, subjects have a one-minute pre-game stage in treatment *A*, in which they can make announcements of contribution levels at any time and as many times as they want to. Each time a subject makes an announcement, the group can see the announcement in real time; only the latest announcement of each subject is shown. When the one-minute stage ends, subjects can choose a nonbinding contribution level simultaneously, as in *B*. Treatment *FC* differs from *A*, in that when the one-minute stage ends, each subject's last announcement becomes their actual contribution level. Treatment *IC* further adds irreversible requirements for the announcements: subjects can only increase their contribution levels during the one-minute interval.[18] Finally, in the *ICC* treatment, each subject's contribution level increases from 0 to 20 at the same pace during the one-minute interval, which is determined by an exogenous clock. They can choose when to opt out from increasing their contributions. Once a subject opts out, his contribution level is finalized and is observed by all group members. In all treatments and at the end of each round, subjects receive feedback on the group's total contribution and their payoff for the round. Table 1 summarizes the experimental treatments.

Table 1: Summary of treatments

Treatments	Announcements	Commitment	Clock	No. of subjects
B	×	×	×	48
A	Yes	×	×	48
FC	Yes	Yes	×	48
IC	Yes	Incremental	×	48
ICC	Yes	Incremental	Yes	48

The goal of the above-mentioned treatment design is to investigate the effects of various factors of the main treatment *ICC*. First, treatment *B* serves as a benchmark. By comparing the contributions of treatments *A* and *B*, we can determine the effect of the announcements. Next, by comparing treatments *FC* and *A*, we can observe the effect of a final commitment

[18] In treatments *A*, *FC*, and *IC*, the default announcement level is zero; that is, if subjects do not make any announcements, their contribution to the public good remain zero. In *IC*, subjects can only increase their announcements. In *A* and *FC*, subjects can choose to either increase or decrease their announcements freely during the one-min interval.

in the announcements. The comparison between treatments *IC* and *FC* can reveal the role of incremental or irreversible commitments. Finally, by comparing the *ICC* and *IC* treatments, we can determine the effect of the clock.[19]

At the end of the experiment, we administer a short survey to collect some demographic information of the subjects. Two out of the 20 rounds are then randomly selected for payment. The subjects earn experimental currency at points in the experiment, and every point is worth ¥0.5.

4.2 Procedures

The experiment was conducted at the Shanghai University of Finance and Economics in October 2019 and September 2020. Chinese subjects were recruited from the subjects pool of the Economic Lab via Ancademy.[20] We ran two to three sessions for each treatment, and 11 sessions were conducted in total.[21] Treatments were randomized at the session level. Depending on the number of people showing up in the experiment, 16, 24, or 32 subjects participated per session. In total, 240 subjects were recruited, most of whom were undergraduate students from various fields of study.

The experiment was computerized using z-Tree (Fischbacher 2007) and conducted in Chinese.[22] Upon arrival, subjects were randomly assigned a card indicating their table number and were seated in the corresponding cubicle. Instructions were displayed on their computer screens. Control questions were conducted to check their understanding of the instructions. The same experimenters were always presented during all the experimental sessions.

After finishing the experiment, subjects received their earnings privately through mobile payment.[23] Average earnings were ¥39 (equivalent to around 6 US dollars), including a show-up fee of ¥15 (around 2 US dollars). Each session lasted between 30 to 45 minutes.

[19]Note that the effect of the clock can be further attributed to two features: (1) a pre-set speed for the incremental commitment, and (2) this speed being equal for each player. Given the intuition of the clock, these two features naturally go hand-in-hand. Therefore, we do no deconstruct this factor further in this study.

[20]Ancademy is a (recruiting) platform for social sciences experiments.

[21]In October 2019, we conducted seven sessions with 160 subjects, including 24 subjects in *B*, 48 subjects in *A*, 40 subjects in *FC*, and 48 subjects in *ICC*. In September 2020, we conducted four sessions with 80 subjects, including 24 subjects in *B*, 8 subjects in *FC*, and 48 subjects in *IC*.

[22]The English translations of instructions and screenshots are provided in Appendix C.

[23]We used Alipay or WeChat pay, according to the preference of each subject, to pay subjects on site. The subjects confirmed receiving of the payment before leaving the laboratory.

5 Results

5.1 Aggregate treatment differences

We first look at how choices differ in each treatment. Figure 1 shows the average contribution level over time for each treatment. As seen in Figure 1, despite similar contribution levels across all treatments at the beginning of the experiments, only the contribution level in the *ICC* treatment exhibits a clearly increasing pattern over time and converges to approximately 75% of the maximal level. The contribution level in *IC* increases slightly over rounds, but does not seem to converge. The average contribution for the *IC* treatment fluctuates around 45% of the maximal level in the second half of the experiment. For the remaining treatments, the contribution levels in treatments *B* and *A* show a declining pattern and converge towards zero over time. The contribution level in the *FC* treatment is more volatile, but also exhibits a declining pattern towards zero. This figure shows that, at the aggregate level, announcements alone (with or without a final commitment) are insufficient for inducing contributions. In contrast, incremental commitment can prevent the contribution from declining under our random matching protocol. More importantly, we can see that adding a clock on top of the incremental commitment is highly effective in improving contributions.

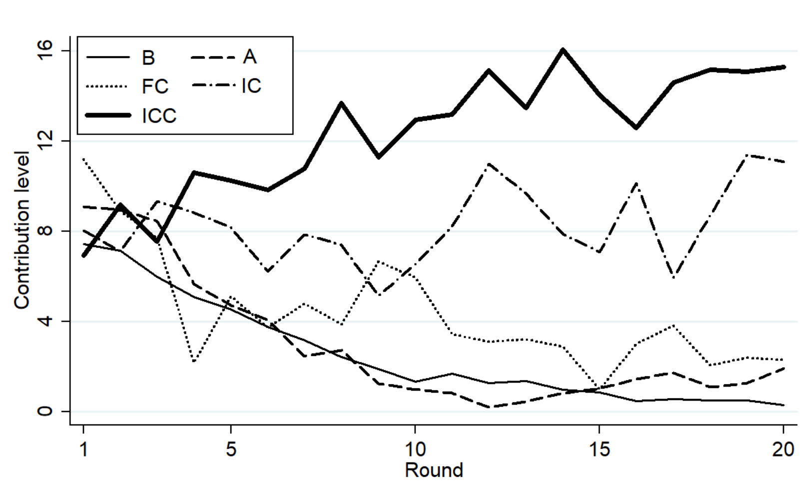

Figure 1: Average contribution over rounds. The average contribution levels are calculated by taking averages across matching groups.

Next, we compare the contribution levels between the treatments in greater detail.

Table 2 shows the average contribution level for rounds 1-10 and 11-20 in each treatment, as well as their comparison using sign-rank tests. In the *ICC* treatment, the average contribution level increases from 52% of the maximal level in rounds 1-10 to 72% of the maximal level in rounds 11-20. The average contribution level in the *IC* treatment increases from 37% to 46% of the maximal level from the first 10 to the last 10 rounds. In contrast, the average contribution levels in treatments *B* and *A* are approximately 20% of the maximal level in the first 10 rounds, and decline to almost zero in the last ten rounds. The average contribution level in the *FC* treatment is slightly higher than in treatments *B* and *A* (approximately 30% in rounds 1-10 and 14% in rounds 11-20), but still much lower than that of treatment *IC* and *ICC*.

Table 2: Average contribution in each treatment and sign-rank test

	B	A	FC	IC	ICC
Rounds 1-10	4.28	4.84	6.01	7.47	10.30
	(1.23)	(1.97)	(3.23)	(3.68)	(4.21)
Rounds 11-20	0.85	1.08	2.72	9.11	14.46
	(0.68)	(0.82)	(2.93)	(1.86)	(5.41)
Sign-rank test	$p = 0.03$	$p = 0.03$	$p = 0.03$	$p = 0.35$	$p = 0.03$

Notes: Each cell shows the all-round average contribution at the matching group level. The standard deviations are shown in parentheses. The sign-rank tests are two-sided tests performed at the matching group level ($n = 12$).

We further check for a learning effect in each treatment. The sign-rank tests show that, in treatments *B*, *A*, *FC*, and *ICC*, the contribution levels differ significantly in the first 10 and the last 10 rounds. In treatments *B*, *A*, and *FC*, the mechanisms become less effective over time, whereas in treatment *ICC*, it becomes more effective over time. This indicates that the effect of the *ICC* mechanism should be stronger had subjects played it for more than 20 rounds. However, in the *IC* treatment, we do not find a significant difference in the contribution levels between the first 10 and the last 10 rounds, indicating that over rounds, it seems to be difficult for subjects in *IC* to discover a method to improve contributions.

Finally, we compare the all-rounds average contribution between treatments by performing two-sided Mann-Whitney tests (tests are performed at the matching group level, and $n = 12$ for all tests). We find that the contribution level in the *ICC* treatment is significantly higher than in all other four treatments (*ICC* vs. *B*, $p < 0.01$; *ICC* vs. *A*, $p < 0.01$; *ICC* vs. *FC*, $p = 0.016$; *ICC* vs. *IC*, $p = 0.078$). The contribution level in the *IC* treatment is significantly higher than in treatments *B*, *A*, and *FC* (*IC* vs. *B*, $p < 0.01$; *IC* vs. *A*, $p < 0.01$; *IC* vs. *FC*, $p = 0.037$). The differences between any pairs of treatments *B*, *C*, and *FC* are insignificant (*B* vs. *A*, $p = 0.423$; *B* vs. *FC*, $p = 0.337$; *A* vs. *FC*, $p = 0.522$).

Result 1. *Contributions converge to zero in treatments B, A, and FC. They remain at around 45% of the maximum level in the IC treatment and increase over time to converge at approximately 75% of the maximum level in the ICC treatment. There is significant learning effect in treatments B, C, FC, and ICC, but not in treatment IC. Subjects contribute significantly more in ICC than in all the other treatments, and more in IC than in B, A and FC.*

5.2 The effect of each factor in *ICC*

In this section, we investigate the effect of announcements, final commitment, incremental commitment, and the clock by comparing treatments *B* and *A*, *A* and *FC*, *FC* and *IC*, and *IC* and *ICC*, respectively.

5.2.1 The effect of announcements: Treatments *B* vs. *A*

First, we examine the effect of announcements by comparing behavioral patterns in treatments *B* and *A*. As can be seen from Figure 1, the highest contribution levels occur for both treatments in the first round and quickly converge to near zero. This result indicates that adding announcements *per se* is insufficient in improving the contribution. Why is this the case? Figure 2 shows the subjects' last announcement levels in the announcement stage and their actual contributions in the choice stage of treatment *A*. It also shows the corresponding comparison in treatment *FC*, which will be discussed later. We can see that subjects contribute much less than their last announcements, indicating that subjects tend to deviate downward from their words. This result suggests that, although the real-time announcement stage induces a highly announced level, it fails to boost the actual contribution because subjects do not stick to their announcements.

This result is consistent with the findings of Bochet et al. (2006), who find that when subjects can make announcements once before playing the public-goods game, their contribution levels remain similar to the baseline game. Although subjects can make announcements for as many times as they want in our setting, it is still insufficient to induce contributions.

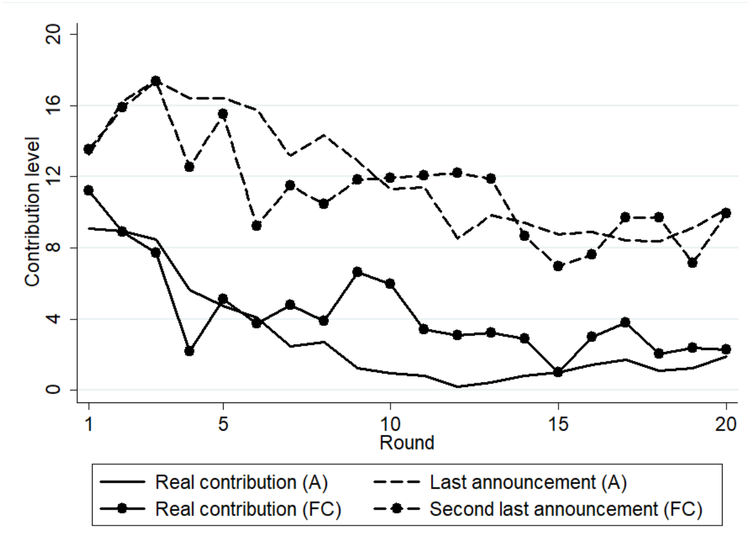

Figure 2: Announcements vs. contributions in treatments *A* and *FC*. The announcements and contributions levels are calculated at a four-player game level.

Result 2. *Adding real-time announcements to the public goods game has no effect on the contributions. In treatment A, although subjects make high announcements, they tend to deviate to near zero in their real contribution.*

5.2.2 The effect of final commitment: Treatments *A* vs. *FC*

Next, we examine the effect of a final commitment by comparing behavioral patterns in treatments *A* and *FC*. Recall that Figure 2 shows the subjects' last announcements and their actual contributions in treatments *A* and *FC*. In treatment *A*, the subjects' last announcements are defined unambiguously as their last update during the real-time stage. However, since the subjects' last announcements in treatment *FC* determine their actual contribution, we instead choose their second to last announcements as their last update instead, because these are the last payoff-irrelevant announcements. Moreover, to qualify the last updated announcement as a deviation from the previous announcements, it must occur at the very end of the one-minute stage. We employ the following empirical criterion for the last payoff-irrelevant announcement: it is the second last announcement if the last revision of the announcement is made within the last 3 seconds of the one-min interval; otherwise, it is the last announcement.[24]

[24]This criterion can be understood by comparing the time distribution of the last announcements in treatment *A* and *FC* (see Figure 9 in Appendix D): Compared to treatment *A*, in treatment *FC*, the last update often takes place in the final 3 seconds (48.54%). Therefore, we consider such last-second updates

Similar to treatment *A*, we can see from Figure 2 that subjects in *FC* tend to deviate downward in their last revisions of announcements; that is, even when subjects can monitor each other in real time, they still deviate to a near zero contribution at the end of the one-minute stage. We perform a test to see if the differences between the actual choices and the last payoff-irrelevant announcements are different between *A* and *FC* (difference in difference test), and the Mann-Whitney test shows that they are significantly different ($p = 0.025, n = 12$).[25]

Our results depart from the findings of Deck and Nikiforakis (2012) and Avoyan and Ramos (2020). In these two studies, real-time monitoring with final commitment helps to achieve efficient coordination in a minimum effort game. However, our game differs from the minimum effort game in that our high-level contribution is not supported by the Nash equilibrium. Therefore, our results indicate that real-time monitoring with final commitment is not sufficient to boost contributions in a public goods game.

Result 3. *Adding a final commitment to real-time announcements has almost no effect on improving contributions. In treatment FC, although subjects start by sending high announcements, they deviate to almost a zero contribution by the end of one-min interval.*

5.2.3 The effect of incremental commitment: Treatments *FC* vs. *IC*

From Figure 1 and Table 2 we can see that after adding incremental commitment to the real-time stage, the contribution level in *IC* no longer declines, but fluctuates at around half of the maximum level over the 20 rounds.

To investigate how subjects behave differently with or without the incremental commitment, we present the average announced level and the cumulative number of updates within the one-min interval in Figure 3 for both treatments. From Figure 3, we observe that although subjects start by announcing a high level at the beginning of the one-min interval in treatment *FC*, they make a sharp decline in the last few seconds, which is

as deviations from one's previous announcements: if a subject makes an update within the last 3 seconds, we treat the second-to-last announcements as the intended actions, and the last revision as the actual contribution. For the remaining cases, we treat the last announcements as both intended actions and real contributions instead.

[25] The average difference between the last announcement and the actual contribution is 9.05 in treatment *A* and 6.92 in treatment *FC*. Although the differences are significantly different between treatments, neither the average contribution nor the average last announcements are significantly different between the two treatments (two-sided Mann-Whitney tests, $p = 0.522$ and $n = 12$ for both tests).

achieved by actively updating. In treatment *FC*, subjects update their announced level for 2.3 times on average, and the updates mostly take place in the first 10 and the last 3 seconds.

The introduction of the incremental commitment brings two changes. First, the announced levels in *IC* increase in a milder manner over time, suggesting that subjects become more cautious when their announcements are irreversible. Second, subjects update less frequently (on average 1.6 times) than in *FC*. However, because subjects cannot decrease their contribution levels in *IC*, such a milder increasing pattern in contribution levels, and a less active updating pattern, still lead to a much higher contribution level by the end of the game, compared to treatment *FC*.

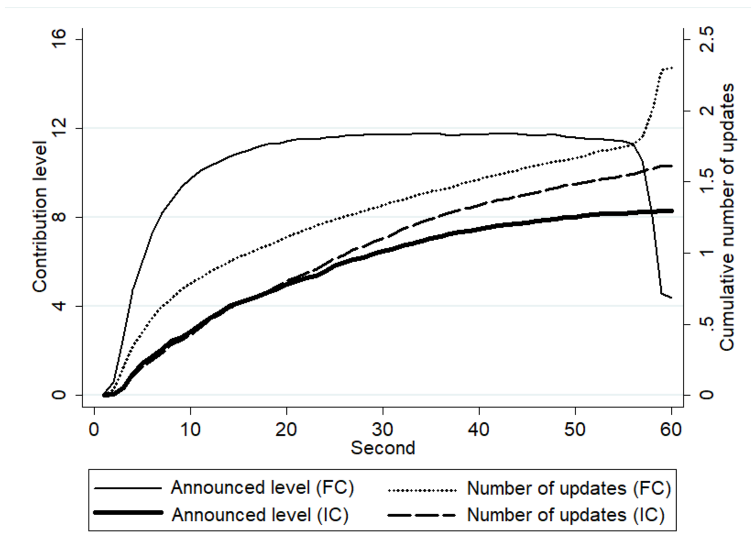

Figure 3: Dynamics within the one-min interval in treatments *FC* and *IC*. The announced contribution levels and the cumulative number of updates are calculated at the individual level.

Our results in treatment IC are in line with those of Dorsey (1992) and Kurzban et al. (2001). Note that our design differs from theirs, in that we adopt a random matching protocol instead of a fixed matching protocol. Arguably, the random matching protocol makes it more difficult for players to cooperate. Our results suggest that the incremental commitment mechanism remains effective even under random matching.

Result 4. *Adding incremental commitment to final commitment and real-time announcements significantly increases the contribution level. In the IC treatment, subjects increase their announced contribution levels slowly and mildly over time.*

5.2.4 The effect of the clock: Treatments *IC* vs. *ICC*

Finally, we examine the effect of adding the clock by comparing he behavioral patterns in treatments *IC* and *ICC*. Figure 4 shows the average contribution of players within the four-player game, who contribute the lowest, second lowest, second highest, and the highest amounts in treatment *IC* (left panel) and *ICC* (right panel).[26][27]

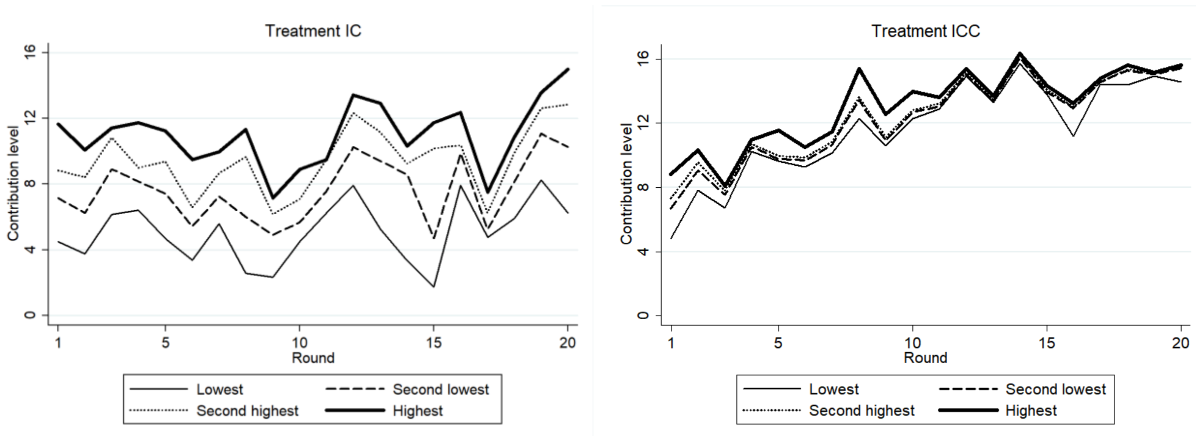

Figure 4: Average contribution level of each player in treatments *IC* and *ICC*. The average contribution levels of the players are calculated at the four-player game level.

First, at the aggregate level, we can see that in treatment *IC*, contributions within a group are highly correlated, indicating that subjects' decisions are influenced by the choices of others in the game.[28] Moreover, a significant gap exists between the highest and lowest contributions within each game, and such a gap does not seem to diminish over time. The average difference between the highest and lowest contribution is approximately six (30% of the total points), suggesting that a significant inequality is present among the subjects.

[26]Note that in treatment *ICC*, the player who contributes the lowest within the four-player game is the first who opts out, the player who contributes the second lowest is the second who opts out, etc.

[27]A similar graph for treatment *FC* can be seen in Figure 10 of Appendix D.

[28]This observation is consistent with conditional cooperation behaviors found in Fischbacher et al. (2001).

In contrast, in the *ICC* treatment, the difference between the lowest and the highest contributions is much smaller. From the right panel of Figure 4, we can infer that this is because, once one of the players opts out, the other three players follow almost immediately. The average contribution gap between every two successive quitters is quite small (0.6 between quitters 1 and 2; 0.15 between quitters 2 and 3; and 0.6 between quitters 3 and 4). In other words, the average quitting time between the two successive quitters falls within 1.8 seconds. Contrary to the pattern of *IC*, the contribution differences within a four-player group diminish over time in *ICC*. Moreover, we can see that the first quitters opt out increasingly late as the rounds progress, which can be explained by learning from past outcomes.

Recall that in Section 3.2, we theoretically analyze the effect of the *ICC* mechanism. The key insight is that it allows subjects to have near-dominant strategies as long as they can forgo a small loss in the game. The predictions vary, depending on the preferences of the subjects. Under standard preferences, if one player has already opted out, the remaining three players have a near-dominant strategy: they stay in until the very end of the one-min interval, unless another player opts out. If subjects are sufficiently inequality averse, then it is a near-dominant strategy for all the players to stay in until the very end of the one-min interval, unless one player opts out.

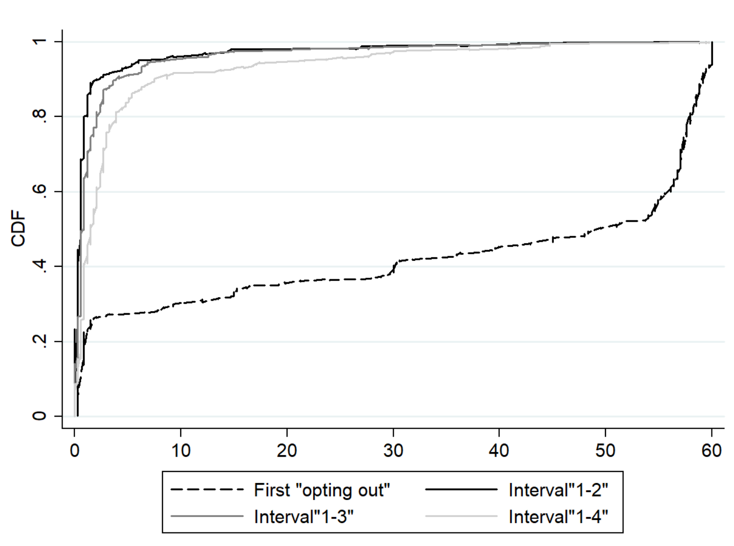

Figure 5: Distribution of the first quitters' opting-out time and their opting-out time difference from later quitters in treatment *ICC*.

To examine whether subjects adopt such near-dominant strategies in practice, we further look at their behavioral patterns at the individual level. Note that it is almost impossible to observe the strategies that subjects actually use in the experiment. Therefore, we look at their reactions before and after exactly one player has already opted out instead. Figure 5 shows the four lines. First, the dashed line depicts the distribution of the opting-out time for subjects who opt out first within their group. In about 40% of cases, the first quitter stays in the contributing phase until the very end of the one-min interval, which fits the predictions under sufficient inequality aversion. Second, the other three lines depict the distribution of the time interval between the first and second quitter (denoted as "Interval 1-2"), the first and third quitter ("Interval 1-3"), and the first and last quitter ("Interval 1-4"). Among all 240 cases, we only find one case that fits the predictions under standard preferences ("Interval 1-2" $\geq$ 55 seconds). By contrast, in over 40% of cases, once a subject opts out, the other three subjects within the group immediately follow; that is, within 1 second ("Interval 1-4" $\leq$ 1 second). In over 80% of cases, the time difference between the first quitter and the last quitter is within 5 seconds. Such behavioral patterns indicate that subjects seem to have sufficiently strong inequality-aversion, and they are often able to adopt a near-dominant strategy, in which they forgo a small monetary loss by opting out only after another player opts out.

Result 5. *Adding a clock to incremental commitment and real-time announcements further increases contribution levels and diminishes the contribution gap between players. The subjects' behavioral patterns are often in line with the predictions under sufficient inequality-aversion.*

6 Conclusion

In this study, we propose a continuous-time mechanism, incremental commitment with a clock, to foster cooperation in public-goods games. To investigate the essential factors that are needed to improve cooperation, we compare it with three other mechanisms: announcements, final commitment and incremental commitment. Theoretically, the Nash equilibrium gives the same prediction for all these setups; ϵ-equilibrium, in contrast, predicts that it is possible to achieve full cooperation with both incremental commitment and a clock. Experimentally, we find that contributions converge to a very high level with incremental commitment and a clock, fail to decay with incremental commitment, but decline to zero in others.

The experimental findings indicate that under real-time monitoring, as long as subjects can deviate to the Nash equilibrium, they may do so unavoidably. With incremental commitment, since the contribution levels are irreversible and are perfectly monitored, it demands strong commitment, which is necessary to induce high contribution in the public-goods game. Moreover, by adding a clock that can increase each player's contribution at the same pace, the incremental commitment works symmetrically to all players and becomes much more effective.

Note that, in our experiment, we employ a matching group of eight subjects, and subjects are randomly matched to play a four-player public-goods game within their matching group. We choose such a group size as a trade-off result between the matching group size and the number of independent matching groups. However, from the perspective of minimizing group-level reputation, a larger matching group size would have been more ideal, because group-level reputation arises more easily when the group size is smaller (Huck and Lünser, 2010). Moreover, since we focus on stranger matching (within a matching group) in this study, a natural future extension is to explore the effect of such mechanisms in partner matching, both theoretically and experimentally. Finally, given that in this study we only use one set of parameters to test our mechanisms, we acknowledge that the results can be further strengthened and the mechanisms can be better understood if it can be extended to more sets of parameters.

The results of this study can potentially be extended to other mechanism design problems in behavioral game theory. First, our study suggests that real-time monitoring can be a reasonable setup for many games, and can be powerful when implemented with essential factors. Second, decision-making under continuous time has a huge potential, both theoretically and empirically.

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Appendices

Appendix A: Proofs

Proof of Proposition 2.

In the paper, we argue that a strategy profile with one player using $k(0, 1-\tau, 1)$, and the three other players using $k(1-\tau, 1-\tau, 1)$ is a subgame perfect ϵ-equilibrium if $\epsilon \geq 24\tau$. Here, we first show that if $\epsilon \geq 24\tau$, for the remaining three players, both $k(1-\tau, 1-\tau, 1)$ and $k(1,1,1)$ are near-dominant strategies when $n_t = 1$. Without loss of generality, we call the first quitter player 1. For player i ($i \neq 1$), suppose that the other two remaining player's strategy is $k_j(s_j, s_j, 1)$ and $k_l(s_l, s_l, 1)$ with $s_j \leq s_l$, then player i's optimal strategy is to opt out at $t = s_j - \tau$, this way, player j will not opt out earlier than s_j, and player i can gain the maximal payoff. Therefore, the maximal payoff is achieved when player i leaves at $s_j - \tau$. By contrast, if player i uses the strategy $k(1,1,1)$, he will end up leaving after observing player j leaves. The maximal payoff loss is the payoff difference between leaving at $s_j - \tau$ and $s_j + \tau$. Note that, by leaving 2τ earlier, player i earns more because his return rate is increased from the public return rate 0.4 to the private return rate 1. The payoff gain for such a time span is $20 * (1-0.4) * 2\tau = 24\tau$. Note that such a maximal payoff gain is achieved when $s_j = s_l$, as only in this case player i does not make player j or player l leave earlier by opting out at $s_j - \tau$.

Therefore, if $\epsilon \geq 24\tau$, $k(1-\tau, 1-\tau, 1)$ and $k(1,1,1)$ are always in the ϵ-best response set, no matter what is the strategy of the other remaining two players: such a strategy is a near-dominant strategy.

Next, given that both $k(1-\tau, 1-\tau, 1)$ and $k(1,1,1)$ are near-dominant strategies in the subgame with $n_t = 1$, for exactly the same reasoning, for the strategy $k(\tilde{s}, \tilde{s}, 1)$, as long as $\tilde{s} \in [1-\tau, 1]$, it is also a near-dominant strategy.

Finally, consider a strategy $k_i(\tilde{s}, \tilde{s}, 1)$ with $\tilde{s} < 1-\tau$ for player i, can it also be a near-dominant strategy for some range of $\tilde{s}$? We know from the above analysis that, by using $\tilde{s} < 1-\tau$, player i will be able to forgo the potential loss if at least one of the other two remaining players opt out earlier (because the maximal loss is 24τ, and we consider $\epsilon \geq 24\tau$). Moreover, by using $\tilde{s} < 1-\tau$, player i also risks that the other two players both plan to leave later than $\tilde{s} + \tau$, and such a strategy trigger the other two players to leave earlier, and hence induce a loss in payoff. The maximal loss in payoff happens when the other two players plan to stay till the end $t = 1$ (that is, $s_j = s_l = 1$), in which player i's best response is to opt out just a bit earlier at $t = 1-\tau$. In this case, the biggest payoff difference by using strategy $k_i(\tilde{s}, \tilde{s}, 1)$ with $\tilde{s} < 1 - \tau$ is represented below.

$$\begin{aligned}
&max\{u(s_i) - u(1-\tau)\} \\
&= 20 * (1-0.4)(1-\tau-s_i) \\
&- 20 * 2 * 0.4(1-\tau-s_i) \\
&= -4(1-\tau-s_i)
\end{aligned}$$

Therefore, such a strategy can only be a near dominant strategy if the maximal payoff difference is smaller than ϵ. That is, $|-4(1-\tau-s_i)| \leq \epsilon$, which yields a condition $s_i \geq 1-\tau-\frac{\epsilon}{4}$ for it to be a near-dominant strategy.

In sum, when $n_t = 1$, for the remaining three players, they all have a near-dominant strategy $k(s, s, 1)$ with $s \in [1-\tau-\frac{\epsilon}{4}, 1]$.

In the above analysis, we have focused only on the equilibrium path. Now we discuss why are the complete strategy profiles of the four players constitute a subgame perfect ϵ-equilibrium also on the off-equilibrium-path. First, note that the parameter s of the first player's strategy $k(0, s, 1)$ denotes the off-equilibrium-path strategy: this player uses the same near-dominant strategy as the other three players when $n_t = 1$. In the equilibrium path, however, the first player will never observes $n_t = 1$ as he is the first to opt out himself. Next, in the three other players' strategy $k(s, s, 1)$, the first s tells what to do when $n_t < 1$, which is also off-equilibrium-path: In the equilibrium path, the first player always opts out at $t = 0$, therefore the three other players will never face the case $n_t < 1$. In this off-equilibrium-path case, given that the first player will always choose to opt out as long as no one has opted out ($n_t < 1$), the best response for the other three players is to always wait (till the end of the one-minute interval) should they observe that $n_t < 1$. Therefore, these strategies are ϵ-best response to each other, both on and off the equilibrium path.

Proof of Proposition 3.

In the paper, we argue that a strategy profile in which each player uses $k(\cdot, 1-\tau, 0)$ is a subgame perfect ϵ-equilibrium if $\epsilon \geq 24\tau + 20\alpha\tau$. Here, we first show that both $k(\cdot, 1-\tau, 0)$ and $k(\cdot, 1, 0)$ are near-dominant strategies for each player. For player i, suppose that the other three player's strategy is $k_j(\cdot, s_j, 0)$, $k_l(\cdot, s_l, 0)$ and $k_q(\cdot, s_q, 0)$ with $s_j \leq s_l \leq s_q$, then player i's best response strategy is to opt out just a little earlier than player j at $t = s_j - \tau$, that is, $k_i(\cdot, s_j - \tau, 0)$. This way, player j will not opt out earlier than s_j, and player i can gain the maximal payoff. When using strategy $k(\cdot, 1, 0)$, player i will instead opt out at $s_j + \tau$, after observing player j opts out. The maximal payoff difference is therefore the difference between leaving at $s_j - \tau$ and $s_j + \tau$. Note that, by leaving 2τ earlier, player i earns more not only because his return rate is increased from the public return rate 0.4 to the private return rate 1, and also because he does not need to suffer a payoff loss due to inequality aversion (because leaving later by time τ than the other players). The maximal payoff gain for leaving 2τ earlier is $20 * (1-0.4) * 2\tau + 3 * 20\frac{\alpha}{3} * \tau = 24\tau + 20\alpha\tau$. Such a maximal payoff gain is achieved when $s_j = s_l = s_q$, as only in this case player i does not make any of the other players to leave earlier by opting out at $s_j - \tau$.

Therefore, if $\epsilon \geq 24\tau + 20\alpha\tau$, then $k(\cdot, 1, 0)$ is always in the ϵ-best response set, no matter what is the cutoff opting out time of the other players. Therefore, such a strategy is a near-dominant strategy. When each player uses such a near-dominant strategy, it is an ϵ-equilibrium.

Next, give that $k(\cdot, 1-\tau, 0)$ and $k(\cdot, 1, 0)$ are both near-dominant strategies, by the same reasoning, it is easy to show that $k(\cdot, \tilde{s}, 0)$ for $\tilde{s} \in [1-\tau, 1]$ is also always a near-dominant strategy.

Finally, consider a strategy $k_i(\cdot, \tilde{s}, 0)$ with $\tilde{s} < 1-\tau$ for player i. By using $\tilde{s} < 1-\tau$, player i will be able to forgo the potential loss if at least one of the other three remaining players opt out earlier (because the maximal loss is $24\tau + 20\alpha\tau$, and we consider $\epsilon > 24\tau + 20\alpha\tau$). Moreover, by using $\tilde{s} < 1-\tau$, player i also risks that the other three players plan to leave later than $\tilde{s} + \tau$, and such a strategy trigger the other three players to leave earlier, and hence induce a loss in payoff for player i. The maximal loss in payoff happens when the other three players have a strategy $k(\cdot, 1, 0)$, and player i's best response is to opt out just a bit earlier at $t = 1-\tau$. And the biggest payoff difference is represented below.

$$
\begin{aligned}
&max\{u(s_i) - u(1-\tau)\} \\
&= 20 * (1-0.4)(1-\tau-s_i) \\
&- 20 * 3 * 0.4(1-\tau-s_i) \\
&= -12(1-\tau-s_i)
\end{aligned}
$$

Therefore, such a strategy can only be a near dominant strategy if the maximal payoff difference is smaller than ϵ. That is, $|-12(1-\tau-s_i)| \leq \epsilon$, which yields a condition $s_i \geq 1-\tau-\frac{\epsilon}{12}$ for it to be a near-dominant strategy.

In sum, the four players all have a near-dominant strategy $k(\cdot, s, 0)$ with $s \in [1-\tau-\frac{\epsilon}{12}, 1]$.

Appendix B: ϵ-equilibrium with non-linear inequality aversion

In the paper, we have already discussed the ϵ-equilibrium with linear-form inequality aversion from Fehr and Schmidt (1999). Here, we generalize the utility function to non-linear functional form, as follows:

$$U_i(x) = 20x_i - \alpha \sum_{j \neq i} \frac{1}{n-1} \max\{(x_j - x_i)^\gamma, 0\} \tag{8}$$

In the above functional form, $\gamma(\geq 1)$ captures the extent by which players' dis-utility increases with the payoff difference between themselves and those who receive a higher monetary payoff. As abovementioned, when $n_t = 1$ in the linear case ($\gamma = 1$), the marginal return by staying in the contributing phase is represented by the following equation:

$$\frac{\partial U_i(x)}{\partial t} = 20 * 0.4 * 3 - \alpha * \frac{1}{3} * 20 \tag{9}$$

In the non-linear case, the equation above becomes the following form:

$$\frac{\partial U_i(x)}{\partial t} = 20 * 0.4 * 3 - \alpha * \frac{1}{3} * 20 * \gamma * \Delta t^{\gamma - 1} \tag{10}$$

The new term, Δt, refers to the time that has passed after one player opts out. Again, the marginal return by opting out from the contributing phase is not influenced by the value of γ, that is,

$$\frac{\partial U_i(x)}{\partial t} = 20 * 1 \tag{11}$$

The three remaining players will prefer to opt out if the value in Equation (10) is lower than that in Equation (11), which yields the following condition:

$$\alpha * \gamma * \Delta t^{\gamma - 1} > 0.6 \tag{12}$$

When $\gamma > 1$, Equation (12) can be re-written as follows:

$$\Delta t > (\frac{0.6}{\alpha * \gamma})^{\frac{1}{\gamma - 1}} \tag{13}$$

By denoting the critical vale $(\frac{0.6}{\alpha*\gamma})^{\frac{1}{\gamma-1}}$ as Δt_c, Equation (13) indicates that when the first player has already opted out at o_1, the remaining three players can stay in the contributing phase until $min\{o_1 + \Delta t_c, 1 - \tau\}$ at latest, provided that the other two players do not opt out.

However, for any player who wants to be the second quitter (e.g., player 2), he may have an incentive to opt out before $min\{o_1 + \Delta t_c, 1-\tau\}$ if he worries that another player(s) will opt out before him. If they opt out before player 2 at $\tilde{t}$, the best response for player 2 would be to opt out at $\tilde{t}-\tau$. However, if he uses the strategy to leave at $min\{o_1 + \Delta t_c, 1-\tau\}$, he will opt out at $min\{\tilde{t}+\tau, 1-\tau\}$. The maximum utility loss compared to the best response occurs when the other two players have the same $\tilde{t}$, with $\tilde{t} \leq 1-2\tau$, and the amount of such a loss is $24\tau + \alpha(20\tau)^{\gamma}$.[29] In summary, when $n_t = 1$, a strategy $k(min\{o_1 + \Delta t_c, 1-\tau\}, 2)$ can guarantee that one forgoes at most $24\tau + \alpha(20\tau)^{\gamma}$ compared to the best response, regardless of the strategy of the other players. According to Definition 3, for $\epsilon \geq 24\tau + \alpha(20\tau)^{\gamma}$, the abovementioned strategy is a near-dominant strategy.

Finally, by backward induction, given that the remaining three players use the abovementioned near-dominant strategy, the best response for the first quitter is to opt out at $t = max\{0, 1-\Delta t_c - \tau\}$. Therefore, we define the following "lag cutoff strategy" and derive the following subgame perfect ϵ-equilibria with near-dominant strategies.[30]

Definition 5 (Lag cutoff strategy)**.** *Denote the opting time of the first quitter as o_1, lag cutoff strategy $l(s_1, s_2, q, \Delta t)$ specifies the conditional cutoff time s_1, s_2, the trigger number q, and the lag interval Δt, which means to "opt out" if (i) $n_t < q$ and $t \geq s_1$, or (ii) $n_t = q$ and $t \geq min\{s_2, o_1 + \Delta t\}$, or (iii) $n_t > q$, and to "stay in" otherwise.*

Proposition 4 (Subgame perfect ϵ-equilibrium with non-linear inequality aversion)**.** *In G^{ICC} where players have non-linear inequality aversion ($\gamma > 1$), and for $\epsilon \geq 24\tau + \alpha(20\tau)^{\gamma}$, there exists a subgame perfect ϵ-equilibrium in which one player has strategy $l(max\{0, 1-\Delta t_c - \tau\}, 1-\tau, 1, \Delta t_c)$ and the other three players have the same strategy $l(1-\tau, 1-\tau, 1, \Delta t_c)$, with $\Delta t_c = (\frac{0.6}{\alpha * \gamma})^{\frac{1}{\gamma-1}}$.*

In the equilibrium outcome of Proposition 4, one player opts out at time $t = max\{0, 1-\Delta t_c - \tau\}$, while the other three players opt out at time $t = 1-\tau$.[31] Note that, as the non-linear index $\gamma \rightarrow_{+} 1$, when $\alpha > 0.6$, the lag interval Δt_c converges to zero, and the subgame-perfect ϵ-equilibrium in Proposition 4 converges to the case with linear inequality aversion (see

[29] The monetary loss is $20 * (1-0.4) * 2\tau = 24\tau$ and the utility loss caused by non-linear inequality aversion is $2 * \frac{\alpha}{2} * (20\tau)^{\gamma} = \alpha(20\tau)^{\gamma}$.

[30] Note that there are more subgame perfect ϵ-equilibria. Here, we characterize an equilibrium with one of the possible near-dominant strategies, just to provide the intuition of subgame perfect ϵ-equilibria under non-linear inequality aversion.

[31] The strategies also best respond to each other off the equilibrium-path, similar to the intuition of the off-equilibrium-path strategies of Proposition 2 (see the proof of Proposition 2 in Appendix A).

Proposition 3); however, when $\alpha < 0.6$, the lag interval Δt_c converges to $+\infty$, and the subgame-perfect ϵ-equilibrium in Proposition 4 converges to the case with a standard preference (see Proposition 2).

Appendix C: Experimental instructions

In this appendix, we provide the experimental instructions and the experimental screenshots that are translated from the original Chinese version.

Instructions (All treatments)

Welcome to this experiment on decision-making. Please read the following instructions carefully. The experiment will last for about 40 minutes. During the experiment, do not communicate with other participants in any means. If you have any question at any time, please raise your hand, and an experimenter will come and assist you privately.

At the beginning of each round, you will be randomly reallocated into a group of four participants. Each participant seat behind a private computer, and no one can learn the identity of one another. All decisions are made on the computer screen. It is an anonymous experiment. Experimenters and other participants cannot link your name to your desk number, and thus will not know the identity of you or of other participants who made the specific decisions.

During the experiment, your earnings are denoted in points. You will receive 30 points at the beginning of the experiment (show-up fee). Your earnings depend on your own choices and the choices of other participants. At the end of the experiment, your earnings will be converted to RMB at the rate: 2 points = 1 RMB. After the experiment, your total earnings will be paid to you in cash privately.

In this experiment, all participants will participate in an allocation game. At the beginning of the game, each participant is endowed with 20 points. During the game, you are asked to allocate these points into two accounts: the private account and the public account. In other words, the sum of the points allocated to the private account and the public account is 20.

The points you allocate to the private account will be exchanged to your earnings at the rate of 1:1, and these earnings will be received only by yourself; the points you allocate to the public account will be exchanged to the public earnings at the rate of 1:1.6, and these earnings will be equally shared by all the four participants in your group, which means each point in the public account will yield an earning of 0.4 to all participants in the group. The total points in the public account equal to the sum of points allocated to the public account by all participants in your group.

In sum, your earnings can be described by the following equation. Your earnings = the points in the private account × 1 + the total points in the public account × 0.4.

Part I (Treatment B)

In the game, you and your group members can decide the allocation in the public account by choosing any number between 0 and 20 (one decimal at most). Meanwhile, the remaining points (20 - your points in public account) will be automatically allocated to your private account.

Part I (Treatment C)

In the game, you and your group members will have 1 minute to make your allocation decision. During this minute, you can send announcements to indicate the amount of points you intend to allocate into the public account, you can do so by sending any number between 0 and 20 (one decimal at most). You can update your intended points to the public account at any time in this minute, and for as many times as you want. You can observe all your group members' latest intended allocations in real-time, and at the same time, your group members can also observe your latest intended allocations immediately after your update.

When the 1 minute interval is ended, you and your group members will decide the final allocation in the public account by reentering the allocation number. Note that, here you can choose any number between 0 and 20 (one decimal at most), and the number does not need to be any of your announcements in the previous 1-minute interval. Here, you and your group members will make this allocation decision at the same time, which means you will not observe each other's allocation choices. Meanwhile, the remaining points (20 - your points in public account) will be automatically allocated to your private account.

Part I (Treatment FC)

In the game, you and your group members will have 1 minute to make your allocation decision. During this minute, you can send announcements to indicate the amount of points you intend to allocate into the public account, you can do so by sending any number between 0 and 20 (one decimal at most). You can update your intended points to the public account at any time in this minute, and for as many times as you want. You can observe all your group members' latest intended allocations in real-time, and at the same time, your group members can also observe your latest intended allocations immediately after your update.

When the 1 minute interval is ended, your final allocation in the public account will determined by the number of your last input; meanwhile, the remaining points (20 - your points in public account) will be automatically allocated to your private account. If you do not put any numbers during the 1-minute interval, the computer will allocate all your 20 points into your private account.

Part I (Treatment IC)

In the game, you and your group members will have 1 minute to make your decision of allocation. During this 1-minute interval, you can send your intended amounts of points in the public account by putting any number between 0 and 20 (one decimal places at most). Secondly, you can update your public allocation at any time in this minute for as many times as you wish. But please note that when updating, you can only increase your allocation of the public account. In other words, during this 1-minute interval, your allocated points in the public account can only be increased or remain unchanged. You can observe all of your group members' most updated intended allocations in real-time, and at the same time your group members can also observe your most updated intended allocations in real-time.

When the 1 minute interval is ended, your final allocation in the public account will determined by the number of your last input; meanwhile, the remaining points (20 - your points in public account) will be automatically allocated to your private account. If you do not put any numbers during the 1-minute interval, the computer will allocate all your 20 points into your private account.

Part I (Treatment ICC)

In the game, you and your group members will have 1 minute to make your decision of allocation. At the beginning of this minute, the points allocated to the public account is set to be 0 for all the participants in your group. During this minute, as time goes on, for each participant the points allocated to the public account will increase in constant pace from 0 to 20, and you can always observe your allocation to the public account in real-time. You can press the "Stop" button at any time in the minute; once you push the button, the increasing of allocation to the public account will stop, and your allocation to the public account will be determined by the time you push the button. Your final allocation to the public account will equal to the allocation presented when you press the "Stop" button, and the remaining points (20 - the points allocated to the public account) will be automatically allocated to your private account.

During this minute, you can observe whether each of your group member has already pressed the "Stop" button in real-time, and for the ones who already "Stop", you can also see each of their allocation to the public account.

Part II (All treatments)

At the end of the game, you can see the total points in the public account and your earnings in the game.

An Example. Suppose that you allocate 12 points to the public account, and the other three participants in your group allocate 8, 12, and 16 points to the public account, respectively. Then the points in your private account are 20 - 12 = 8, and the total points in the public account are 12+8+12+16=48. Your Earnings = 8 (points in the private account) x1 + 48 (the total points in the public account) x 0.4 = 27.2(The numbers in the example are randomly generated by the computer.)

You will play the same game as described above for 20 rounds in total. In every round, you will be randomly matched with three participants. This means that members in your group may be different in each round.

In each round, the identity of participants in the group will be represented by A, B, C, D. For the next round, the identity of each participant will be randomly reallocated again. In other words, all the participants are anonymous to each other.

At the end of the experiment, 2 out of the 20 rounds will be randomly chosen by the computer to determine your earnings. Your earnings in this experiment equal the sum of the points you earn in these two rounds plus the show-up fee (30 points). The points you earn will be converted to RMB at the rate: 2 points = 1 RMB. Your total earnings (RMB) = Your total points/2.

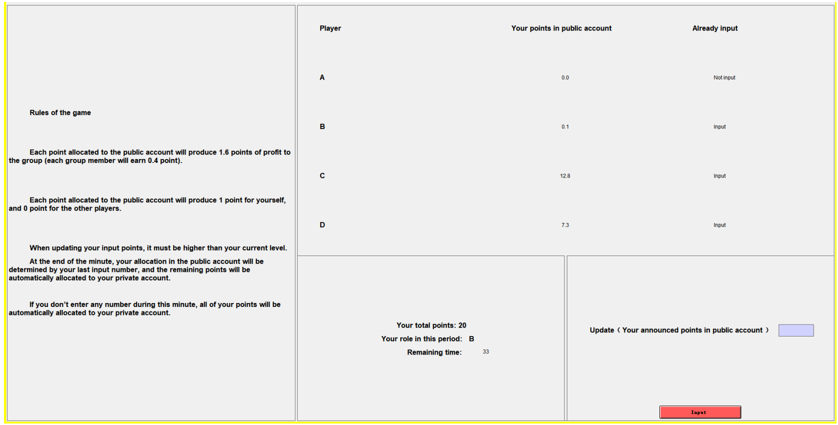

Figure 6: Screenshot of treatments *IC*.

Figure 7: Screenshot of treatment *ICC*.

Appendix D: Supplemental figures and tables

In this appendix, we provide the supplemental figures that are useful for understanding the experimental results.

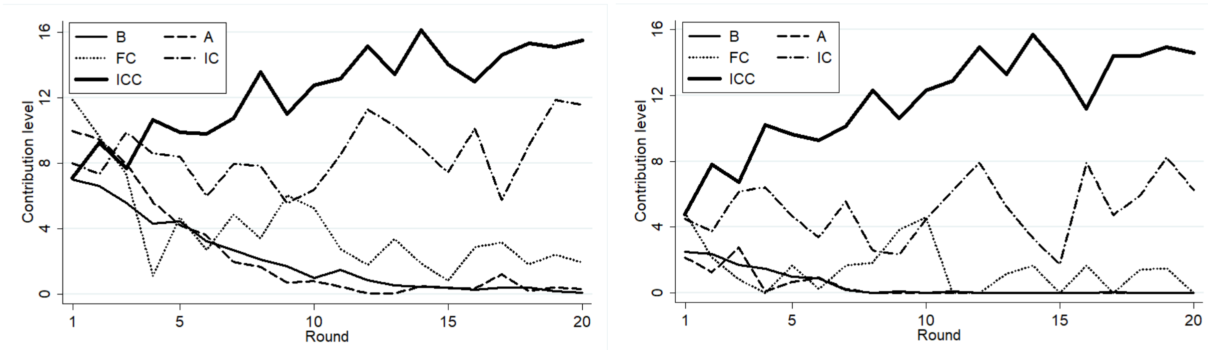

Figure 8: Median (left) and minimum (right) contribution over rounds.

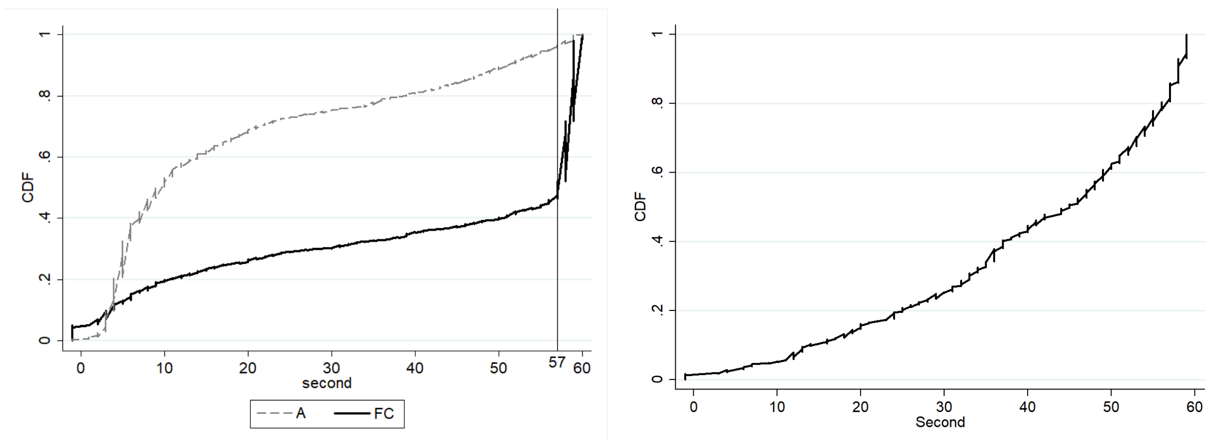

Figure 9: Time distribution of each player's last announcement in *A* and *FC* (left), and time distribution of each four-player game's last announcement in *IC* (right).

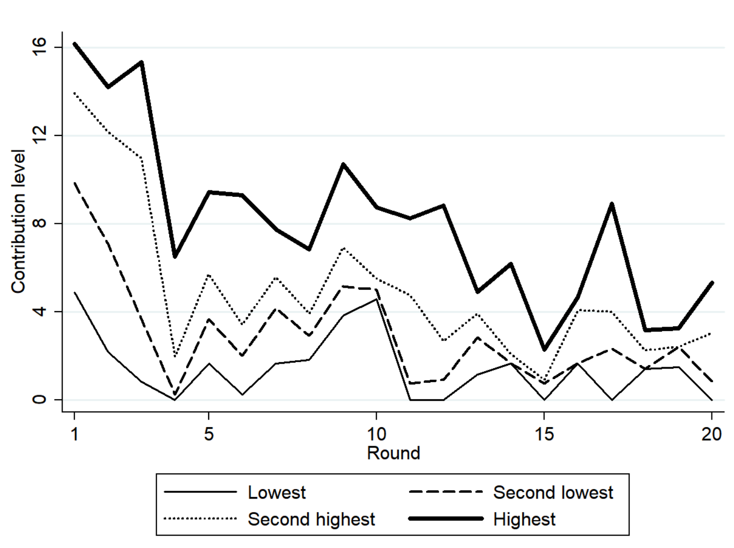

Figure 10: Average contribution level of each player in treatment *FC*. The average contribution levels of the players are calculated at the four-player game level.