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. Within a fixed period, a clock ensures that contributions increase simultaneously for every player, and players can choose when to stop, while their actions are observed by others in real time. We show both theoretically and experimentally that this mechanism is very effective in improving the contribution. Three critical factors may play a role: cheap talk, incremental commitment, and the clock. We further decompose these factors and find that cheap talk alone is not effective, while incremental commitment and the clock each account for 60% and 40% of the total effect, respectively.

Keywords: Public goods, continuous time, incremental commitment, cheap talk.

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 efficiently contribute to a public good. For example, building a dam that benefits people living around it requires everyone to contribute, and fighting global warming problem requires all countries to reduce their carbon emissions. However, the problem is challenging because non-contribution to the public good is in everyone's private interest, which is supported by the Nash equilibrium. Many experimental studies confirm that contributions to public goods tend to converge to a very low level once people gain experience playing the game.[1] On the other hand, many studies find effective mechanisms that can improve contributions to public goods.[2] These mechanisms may involve punishment or reward institutions, endogenous sorting partners, or pre-game communication, 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, the others can observe it in real time.[4] Each player's stopping decision is irreversible, and it determines one's contribution to the public good; the earlier one stops, the less one contributes.

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 as well. Moreover, in a continuous-time environment, players may become tolerant of earning a bit less than others by choosing to stop only after observing others' stopping actions, which is consistent with the intuition of ϵ-equilibrium. Together, this mechanism can potentially induce a high contribution. There are many economic situations in which such a mechanism could be implemented. For example, fundraising institutions may employ such a program, in which they can slowly increase each participating donor's contribution every day, and donors can opt out whenever they

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

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

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

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

like. During the process, the donors can always observe how many people choose to opt out or stay in the program.

In this mechanism, four factors can potentially improve the contribution. First, since each player's actions are perfectly observed by others, they can signal their intended actions. We call this "cheap talk." Second, because players' stopping actions determine their actual contribution in the game, there is "final commitment." Third, since players can only increase their contribution within a fixed time period, there is "incremental commitment." Finally, there is an exogenous "clock" which ensures that each player's contribution increases at the same rate. Therefore, we call our main mechanism *Incremental Commitment with a Clock*.

In order to understand which factors are critical in inducing contribution, we decompose our main mechanism into three other setups. The first is *Cheap talk*, in which players have one minute to send announcements of intended actions for as many times as they like, where the latest announcement is always observed by the entire group. After this minute, players choose their contributions, which are not constrained by their announcements. The second setup is the *Final Commitment*. This setup is similar to *Cheap talk*, and the only difference is that players' last announcements in the one-minute stage become their actual contribution in the game. The next setup is the *Incremental Commitment*. This setup is like the *Final Commitment*, except that when updating announcements, players can only increase their contributions compared to their own previous announcements. Finally, we also include the game without any mechanisms as a *Baseline* setup.

Theoretically, the Nash equilibrium predictions are the same for all the five setups. That is, players contribute zero to the public good. However, since the decision time is continuous in *Incremental Commitment with a Clock*, we apply ϵ-equilibrium to make the theoretical predictions for this mechanism. We find that, with standard preferences and in equilibrium, one player stops contributing at the very beginning of the time, whereas the other three players have a near-dominant strategy to continue contributing unless a second player stops. The intuition is that, by continuing to contribute when there are still three players, the total return rate is 1.2 (0.4×3); however, if one stops contributing, she anticipates that the other two will follow immediately, and the return rate of the private account is only 1.0. 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 equilibrium, everyone may contribute fully to the public good.[5] In

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

summary, ϵ-equilibrium predicts that it is possible to sustain high contribution levels in *Incremental Commitment with a Clock*, especially when players are sufficiently inequality-averse. However, there are many other equilibria in which players fail to contribute as much. Therefore, it remains an empirical question 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, and 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, they 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.[6] We use this design as we want to tease out the effect of reputation, and to make the game comparable to a one-shot game.

The experimental results show that in treatments *Baseline*, *Cheap talk*, and *Final Commitment*, contributions converge to zero over time. Though subjects tend to announce a high intended contribution in the latter two, 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 around 45% of the maximal level. Finally, in treatment *Incremental Commitment with a Clock*, although contribution levels are not different from the other treatments in the beginning, they increase over time and reach approximately 75% of the maximal level by the last few rounds. We further find that the behavior patterns are mostly consistent with the predictions by the ϵ-equilibrium with sufficiently strong inequality aversion, and most subjects tend to 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 contributions are low, suggesting that our main mechanism and its underlying near-dominant strategy are behaviorally obvious for the subjects. In sum, our experimental findings indicate that, under real-time monitoring, cheap talk alone, with or without final commitment, is not sufficient to boost contribution. In contrast, incremental commitment and the clock are critical, each accounting for about 60% and 40% of the total improvement in contribution, respectively.

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

[6] 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 provides the results. Section 6 concludes.

2 Related literature

There are many experimental studies on public-goods games; see Ledyard (1995) and Chaudhuri (2011) for two critical surveys of public-goods experiments. There are three established facts from these studies. First, subjects contribute more than the theoretical prediction in one-shot games or at the beginning of repeated games. Second, the contributions decline steadily over time to the Nash equilibrium predictions under both fixed partnerships and random re-matching. Third, most people are willing to contribute if their partners contribute (Fischbacher et al. 2001).

Later studies demonstrate many effective mechanisms to help achieve high contribution in public-goods games. First, allowing punishment or reward can largely improve contribution, especially under fixed-partnerships (e.g., Fehr and Gächter 2000; Masclet et al. 2003; Walker and Halloran 2004; Gunnthorsdottir et al. 2007; Nikiforakis 2008; Yang et al. 2018). Second, pregame communication, especially free-format communication and face-to-face communication, can improve contribution (e.g., Isaac and Walker 1988a; Wilson and Sell 1997; Bochet et al. 2006; Denant-Boemont et al. 2011; Haruvy et al. 2017). Third, when subjects can choose their partners based on past behaviors, or when they can endogenously sort into different groups, they contribute more compared to exogenously determined group composition (e.g., Gächter and Thöni 2005; Gunnthorsdottir et al. 2007; Charness and Yang 2014). Our *Cheap talk* treatment falls into the second category, and is especially related 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 in the pre-game stage.

The most relevant work to ours are the experimental studies on dynamic public-goods games. Dorsey (1992) is the first paper that introduces real-time monitoring in public-goods games. In a three-minute stage, subjects can only increase their contribution level, and their actions are perfectly monitored by others. They find that such an irreversible mechanism can prevent contribution from rapid decay, whereas a reversible condition fails to do so. Our *Incremental Commitment* mechanism is similar to that of Dorsey (1992), except that we employ a one-minute stage and random matching. Kurzban et al. (2001) replicate the design of Dorsey (1992) and study the effect of different information disclosures. They provide information on either the highest or the lowest contribution in a group. They find that only the combination of providing the lowest contribution and the irreversible setting can eliminate the decay trend of contribution.[7] Later, Tan et al. (2015) further extend Dorsey (1992) by introducing the opposite version of the irreversible setting, in which subjects can only decrease their contribution from the maximal level. They find that the irreversible condition is only effective among inexperienced subjects, whereas the opposite condition is effective only among experienced subjects. Finally, based on the theoretical work of Marx and Matthews (2000), Duffy et al. (2007) study how multiple contribution rounds affect contribution, and they find that subjects contribute more in a dynamic public good game compared to a static one.[8] Our *Incremental Commitment with a Clock* mechanism is similar to these studies in that subjects can only increase their contribution, and therefore share the spirit of gradualism in contribution. However, our mechanism differs in two ways: first, players only choose when to stop their contribution from increasing exogenously, instead of choosing whether, when and how much they want to increase their contribution. This simplifies the decision that subjects have to make. Second, our mechanism works in continuous time, and by applying the ϵ-equilibrium in such a continuous-time setup, high contribution levels can always be supported regardless of the behavioral types of the players.[9]

There are a handful of experimental papers with real-time monitoring but in other games. Deck and Nikiforakis (2012) study how real-time monitoring affects behaviors in a minimum-effort coordination game. In a one-minute pregame phase, subjects can choose their actions and change them freely at any time; these actions can be either perfectly or imperfectly observed by the other group members. Our *Final Commitment* setup is similar to their perfect monitoring treatment. They find that when subjects can perfectly monitor the choices of all the other group members, efficient coordination can be largely achieved. Avoyan and Ramos (2020) also introduce a one-minute monitoring phase in a minimum-effort game, but subjects in their game only have the possibility to revise their actions with an exogenously determined probability. They find that when the opportunity of revisions is probabilistic, it serves as commitment and induces coordination at the

[7]Cason and Zubrickas (2019) also study a public goods game in real time setting with irreversible contributions, but they focus on the effect of refund bonuses. They find that the refund bonus policy is more effective in the real time settings compared to static ones.

[8]Choi et al. (2008) also find that people contribute more in a dynamic voluntary contribution game, and their experimental results are best explained by symmetric Markov perfect equilibrium and Quantal response equilibrium.

[9]Behavioral types refer to conditional cooperators, free-rides, etc.

Pareto optimal equilibrium. Moreover, they further test a real-time cheap talk mechanism, in which the last actions are nonbinding. They find that such a cheap talk mechanism under real-time monitoring is not as effective as the mechanism with commitment. These two studies show that real-time monitoring is highly effective in minimum-effort games, especially when the actions in the monitoring stage are binding. Compared to minimum effort games, it is arguably more difficult to achieve the socially desirable outcome in public-goods games because it is not supported by Nash equilibrium.

Our main mechanism is also related to experimental studies of continuous games. Friedman and Oprea (2012) first study a two-person continuous time prisoner dilemma game, in which players receive flow payoffs accumulated over 60 seconds. They find that subjects reach a very high cooperation rate in the continuous dilemma. Later, Oprea et al. (2014) extend the same payoff structure to a public goods game, and increases the length of the payoff accumulation stage to 10 minutes. They find that the effect of a continuous game found in a prisoner dilemma game is muted in the public goods game. However, when adding communication in the continuous game setting, subjects contribute at a very high level. There are two major differences between the games in Friedman and Oprea (2012) and Oprea et al. (2014): First, the number of players increases from two to four; second, the strategy space changes from binary to the entire contribution interval. Both differences potentially make it harder for players to sustain cooperation.[10] Compared to the continuous public goods game in Oprea et al. (2014), our main mechanism also allows a continuous time setup, but is different in two fundamental ways. First, in our game, payoffs are not accumulated over time. Second, our mechanism provides a stronger force for players to condition their actions on the other players in the group, as players cannot reverse their contribution to a lower level over time.

Finally, the theoretical framework of our main mechanism applies ϵ-equilibrium, which has been studied in theoretical papers such as Radner (1986), Simon and Stinchcombe (1989), and Bergin and MacLeod (1993).[11]

[10]See more experimental work on continuous games in Bigoni et al. (2015), Calford and Oprea (2017) and Leng et al. (2018), among others.

[11]Many experimental studies of continuous games, such as Friedman and Oprea (2012) and Calford and Oprea (2017), also apply ϵ-equilibrium to construct strategies and make theoretical predictions.

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 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, players choose their contribution level simultaneously in the normal-form game G. It is a dominant strategy to choose zero contribution. Therefore, there is a unique Nash equilibrium, in which all players choose zero contribution.

3.1.2 Cheap talk

In the *Cheap talk* setup, players choose their contribution level simultaneously after the one-minute cheap talk phase. No matter what they say in the cheap talk phase, it is still a dominant strategy to choose zero contribution. Therefore, the Nash equilibrium is the same as in *Baseline*.

3.1.3 Final commitment

In the *Final Commitment* setup, in a one-minute phase, the last announcement made by each player is payoff-relevant and becomes their actual contribution in the game. Therefore, in this game, no matter what announcements are sent by players previously, by the end of one minute, it is still a dominant strategy to choose zero contribution. 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. We can show that any outcome in which at least one player contributes a positive amount cannot be a Nash equilibrium outcome. Therefore, there is a unique Nash equilibrium outcome, in which each player contributes zero to the public good. The detailed proof can be found in Appendix A.

3.1.5 Incremental commitment with a clock

In the *Incremental Commitment with a Clock* setup, an exogenous clock increases contribution at the same pace for all players, and players can choose when to opt out from increasing their contributions. Once a player opts out, his contribution is finalized at that time. Again, we can show that there is a unique Nash equilibrium outcome, in which each player contributes zero. The detailed proof can be found in Appendix A.

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, and can adjust their strategies accordingly. For example, if player i opts out immediately after observing that player j just opts out (with a reaction time lag τ), player i's payoff is just a little bit lower than player j, given that τ is very small. It is therefore reasonable to apply the ϵ−equilibrium here. 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, for player i, suppose 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.*

Applying the ϵ-equilibrium solution concept to *Incremental Commitment with a Clock* yields interesting predictions. This is because when there are three remaining players in the contributing phase, as long as they all opt out at the same time, a player can only gain a small payoff by deviating to opting out a bit earlier. If he deviates to opt out much earlier than the other two players, they will follow immediately and therefore result in a lower payoff. However, it is not possible for all four players to stay in the contributing phase, as when exactly one player opts out, the other three still find that it is beneficial to stay in; therefore, a player's dominant strategy is to opt out at $t = 0$ and free-ride on the other three players. For the other three players, if they opt out at the same time or with little time lag, it could become an ϵ-equilibrium. In fact, without knowing the cutoff strategies of the other two players, it can be a near-dominant strategy for each of the three players to stay in the contributing phase, unless someone else opts out first. Below, we characterize the ϵ−equilibria with standard preferences.

Proposition 2 (ϵ-equilibria with standard preferences)**.** *In Incremental Commitment with a Clock, for $\epsilon \geq 12\tau$, there exist ϵ-equilibria in which one player has $s_1 = 0$, and the other three players have the same cutoff strategy $K(\tilde{s})$, that is, "Opt out" when $n(-i) \geq 2$ or $t \geq \tilde{s}$ ($0 \leq \tilde{s} \leq 1$), and "Stay in" otherwise. $n(-i)$ is the number of opted out players other than oneself. For $\epsilon \geq 24\tau$, $K(1)$ is a near dominant strategy for the last three players.*

In the equilibria characterized in Proposition 2, exactly one player opts out at $t = 0$, and the other three players use an identical cutoff strategy. When ϵ is large enough, it is a near dominant strategy for the last three players to stay in unless a second player opts out. Note that since the best response set becomes larger with ϵ-equilibrium, there are more equilbria. In fact, as long as the three players use a cutoff with a very small time lag, it can become an equilibrium. In this proposition, we only characterize the equilibria in which the last three players use the same strategy.

3.2.1 ϵ-equilibrium predictions with inequality aversion

In the above theoretical analysis, we assume that players have standard preferences. That is, players only care for their own monetary payoffs. In the equilibrium characterized in Proposition 2, there is a strong asymmetry between the player who opts out at $t = 0$ and the other three players who opt out later. In this equilibrium, one player free-rides on the other three players. Current empirical evidence on inequality aversion suggests that it is challenging for such asymmetric equilibria to occur. As long as the remaining three players are sufficiently inequality-averse, they might rather opt out as soon as the first player opts out, so as to reach a more fair result even by sacrificing some monetary payoff.

In this section, we consider the theoretical predictions if players are inequality-averse. We use the utility function from Fehr and Schmidt (1999) as follows: We assume that all the players have homogeneous inequality-averse level α, which captures how one dislikes that others receiver a higher monetary payoff than himself.[12]

$$U_i(x) = x_i - \alpha \sum_{j \neq i} \frac{1}{n-1} \max\{x_j - x_i, 0\} \tag{2}$$

Consider the equilibrium characterized in Proposition 2. For what values of α will the equilibria break down? After the first player (the free rider) opts out at $t = 0$, the remaining players face a tradeoff by keep staying in the contribution phase. Although staying in increases their monetary payoffs effectively, it also enlarges the payoff difference between them and the free-rider. The rate of the former is 1.2 (3×0.4), and the payoff difference rate is 1 (since the free rider enjoys the same benefit from the public goods, but he can also receive extra payoff from his own private account). The sum of the marginal gain by staying in is presented in the equation below:

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

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

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

The equilibria in Proposition 2 will break down when staying in (equation 3) has a lower value than opting out (equation 4), which yields the following condition:

$$\alpha > 0.6 \tag{5}$$

If players are sufficiently inequality-averse ($\alpha > 0.6$), all the asymmetric equilibria in Proposition 2 break down. This suggests that when one player opts out from the contributing phase, all the other three players will also opt out as soon as possible. As

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

a result, it can be a near-dominant strategy for all the players to opt out at $t = 1$ unless someone opts out earlier. Below, we characterize the ϵ−equilibrium with (sufficiently strong) inequality aversion.

Proposition 3 (ϵ-equilibria with inequality aversion)**.** *In Incremental Commitment with a clock where players are sufficiently inequality averse ($\alpha > 0.6$), for $\epsilon \geq 12\tau$, there exist ϵ-equilibria in which all players use the same cutoff strategy $K(\tilde{s})$, that is, "Opt out" when $n(-i) \geq 1$ or $t \geq \tilde{s}$ ($0 \leq \tilde{s} \leq 1$), and "Stay in" otherwise. $n(-i)$ is the number of opted out players other than oneself. For $\epsilon \geq 24\tau + \frac{20\alpha\tau}{3}$, $K(1)$ is a near dominant strategy for all players.*

In the equilibria characterized in Proposition 3, players use a symmetric strategy, that is, their cutoff strategies are the same $s_1 = s_2 = s_3 = s_4 = \tilde{s}$ for any $0 \leq \tilde{s} \leq 1$. Again, when ϵ is large enough, it is a near-dominant strategy for all players to stay in unless one player opts out.[13]

In summary, in all the setups, the Nash equilibrium outcomes are identical: All players contribute zero to the public good. In contrast, when applying the ϵ-equilibrium solution concept to *Incremental Commitment with a Clock*, we find that any contribution levels can be supported. Moreover, it can be a near-dominant strategy for players to stay in until enough players opt out. With sufficiently strong inequality aversion, even full contributions can be supported. In the remaining parts of the paper, we implement these mechanisms to the laboratory to see if we can find empirical support.

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. The treatments are *B (Baseline)*, C (Cheap talk), *FC (Final Commitment)*, *IC (Incremental Commitment)*, and *ICC (Incremental Commitment with a Clock)*.

Each subject participates in only one of the treatments. In the experiment, all subjects play the same public-good game for 20 rounds.[14] In this game, subjects 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

[13]Similar to Proposition 2, there are more equilibria that we do not characterize. In fact, if the four players use a cutoff with a very small time lag, it can become an equilibrium.

[14]The game is described by equation 1 in Section 3.

for all treatments. Subjects are randomly assigned to a fixed matching group of eight. In each of the 20 rounds, the eight subjects within a matching group are randomly divided into two four-player groups to play the experimental game. Thus, subjects cannot form long-term partnerships or build a reputation in their matching group because they cannot identify one another.

The five treatments differ in the mechanism before playing the public-goods game. In treatment *B*, subjects directly choose their contribution simultaneously. In treatment *C*, subjects first experience a cheap-talk stage before choosing their contribution levels. At this stage, they have one minute to announce their intended contribution levels. Subjects can announce and update their intended contribution at any time and for as many times as they want to. Each time a subject makes an announcement, the group can see the announcement immediately (in real-time); only the latest announcement of each subject is shown at any time of this stage. When this one-minute cheap talk stage ends, subjects can choose their actual contribution level simultaneously as in *B*, and their choices are not constrained by their announcements. Treatment *FC* only differs from *C* in that, when the one-minute stage ends, each subject's last announcement becomes their actual contribution level. Therefore, compared to treatment *C*, the last announcement in this treatment serves as a commitment. Treatment *IC* further adds irreversible requirements for the announcements of subjects: during the one-minute stage, subjects can only increase their contribution levels (compared to one's previous announcement), and each subject's last announcement will become their actual contribution in the game. Finally, in treatment *ICC*, subjects again enter a one-minute stage. In this minute, each subject's contribution level increases from 0 to 20 at the same pace, which is determined by an exogenous clock. They can choose when to stop from increasing their own contribution by pushing the "opting out" button at any time; the earlier one pushes the button, the lower is his contribution level. When a subject presses the "opting out" button, all subjects in the group can observe it immediately. After a subject opts out, his contribution level is finalized and determined by the time he opts out. In all treatments, at the end of each round, subjects receive feedback on the group's total contribution and their payoff in this round. Table 1 summarizes the experimental treatments.

The goal of the above treatment design is to investigate the effect of different factors in the main treatment *ICC*. First, treatment *B* serves as the benchmark. By comparing the contribution levels in treatments *C* and *B*, we can determine the effect of cheap talk only. Next, by comparing treatments *FC* and *C*, we can see how final commitment affects

Table 1: Summary of treatments

Treatments	Cheap talk	Commitment	Clock	No. of subjects
B	×	×	×	48
C	Yes	×	×	48
FC	Yes	Yes	×	48
IC	Yes	Incremental	×	48
ICC	Yes	Incremental	Yes	48

contribution. Then, the comparison between treatments *IC* and *FC* can reveal the role of incremental commitment in improving contribution. Finally, by comparing treatments *ICC* and *IC*, we can learn the effect of the clock.

At the end of the experiment, we administer a short survey, collecting some background information. Two out of the 20 rounds are then randomly selected for payment. Subjects earn experimental currency in 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. Chinese subjects were recruited from the subjects pool of the Economic Lab. We ran two or three sessions for each treatment, in total 11 sessions were conducted. Treatments were randomized at the session level. Depending on the number of people showed up at 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 studies.

The experiment was computerized using z-Tree (Fischbacher 2007) and was conducted in Chinese.[15] 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 through mobile payment privately.[16] Average earnings were ¥39 (equivalent to around 6 US dollars), including

[15]The English translations are provided in Appendix B.

[16]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.

a show-up fee of ¥15 (around 2 US dollars). Each session lasted between 30 to 45 minutes.

5 Results

5.1 Treatment differences

We first look at how choices differ in each treatment. Figure 1 presents the average contribution level over time for each treatment. We can see from Figure 1 that, despite similar contribution levels across all treatments at the beginning of the experiments, only the contribution level in treatment *ICC* exhibits a clear increasing pattern over time and converges to around 75% of the maximal level. The contribution level in *IC* increases slightly over rounds, but does not seem to converge. The average contribution in treatment *IC* fluctuates around 45% of the maximal level in the second half of the experiment. In the remaining treatments, contribution levels in treatments *B* and *C* show a declining pattern, and converge toward zero over time. The contribution level in treatment *FC* is more volatile, but also exhibits a declining pattern towards zero. This figure shows that, at the first look, cheap talk alone, with or without final commitment, is not sufficient to induce contribution. In contrast, incremental commitment can prevent 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 contribution.

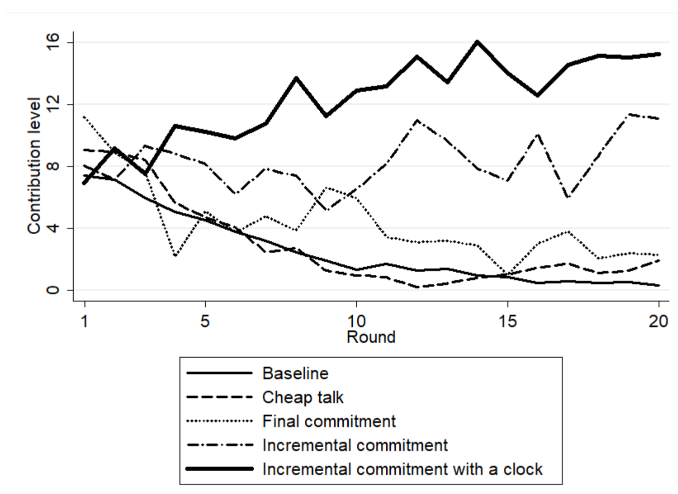

Figure 1: Average contribution over rounds. The average contribution levels are calculated by taking averages across matching groups.

Next, we compare the contribution levels between treatments in greater detail. Table 2 shows the average contribution level in rounds 1-20 and 11-20 by treatment, respectively. Throughout the 20 rounds, the average contribution level in treatment *ICC* reach 62% of the maximal level, and increase to about 72% of the maximal level in the second half of the experiment. The average contribution level in treatment *IC* reaches 41% of the maximal level and increases to 45% of the maximal level in the last ten rounds. By contrast, average contribution levels in treatments *B* and *C* are below 15% of the maximal level throughout the 20 rounds, and decline to almost zero in the last ten rounds. The average contribution level in treatment *FC* is slightly higher than in treatments *B* and *C* (about 25% in all rounds and 15% in the second half), but still much lower than that in treatment *IC* and *ICC*.

Table 2: Average contribution in each treatment

	B	C	FC	IC	ICC
Rounds 1-20	2.57	2.96	4.37	8.29	12.38
	(0.84)	(1.05)	(3.00)	(1.62)	(4.58)
Rounds 11-20	0.85	1.08	2.72	9.11	14.46
	(0.68)	(0.82)	(2.93)	(1.86)	(5.41)

Notes: Each cell shows the all-round average contribution at the matching group level. Standard deviations are in parentheses.

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

Finally, to determine the effect of each factor, we calculate the net improvement of efficiency by each of these factors using data from the last ten rounds. By comparing the average contribution levels in each treatment, we find out that cheap talk, final commitment, incremental commitment, and clock each account for 2%, 12%, 47%, and

39% of the total improvement, respectively.[17] Furthermore, given that contributions in treatments *B* and *C*, treatments *C* and *FC* are not statistically different, we conclude that the factors that significantly improve the contribution are (incremental) commitment and the clock, each of which accounts for about 60% and 40% of the total effect.

Result 1. *Contributions converge to zero in treatments B, C, and FC, remain at around* 45% *of the maximum level in treatment IC, and increases over time and converges to approximately* 75% *of the maximum level in treatment ICC. Subjects contribute significantly more in ICC than in IC, and more in IC than in all the other three treatments. Incremental commitment and the clock each account for 60% and 40% of the improvement in contribution, respectively.*

5.2 Within treatment analysis

In this section, we investigate behavior patterns within each treatment, and test if they are consistent with the theoretical predictions.

5.2.1 Baseline

In treatment *B*, as can be seen from Figure 1 and Table 2, subjects contribute about 8 out of 20 points to the public goods in the first round, and they contribute less and less over time, reaching almost zero contribution by the last few rounds. This result is consistent with previous experimental findings in public-goods games under random matching (see Ledyard 1995, Chaudhuri 2011).

Result 2. *In B, contribution converges to zero over time.*

5.2.2 Cheap talk

In treatment *C*, as can be seen from Figure 1 and Table 2, subjects contribute a very similar amount compared to treatment *B*. In the first round, they contribute approximately 9 out of 20 points to the public good, and their contributions converge to zero over time.

Next, we examine the behavior pattern in treatment *C*. Figure 2 shows subjects' last announcements of intended actions in the cheap talk stage, and their actual contributions in the choice stage. It also shows the corresponding comparison in treatment *FC*,

[17] The total improvement of contribution level is $14.46 - 0.85 = 13.61$. The effect rate of cheap talk is $\frac{1.08-0.85}{13.61} = 2\%$. The effect rate of final commitment is $\frac{2.72-1.08}{13.61} = 12\%$. The effect rate of incremental effect is $\frac{9.11-2.72}{13.61} = 47\%$. The effect rate of the clock is $\frac{14.46-9.11}{13.61} = 39\%$.

which we will discuss later. We can see that subjects contribute much less than their last announcements, indicating that subjects tend to deviate downward from their intended actions. This result suggests that although the real-time cheap talk stage induces a high intended contribution, it fails to boost actual contribution as subjects do not stick with their intended actions.

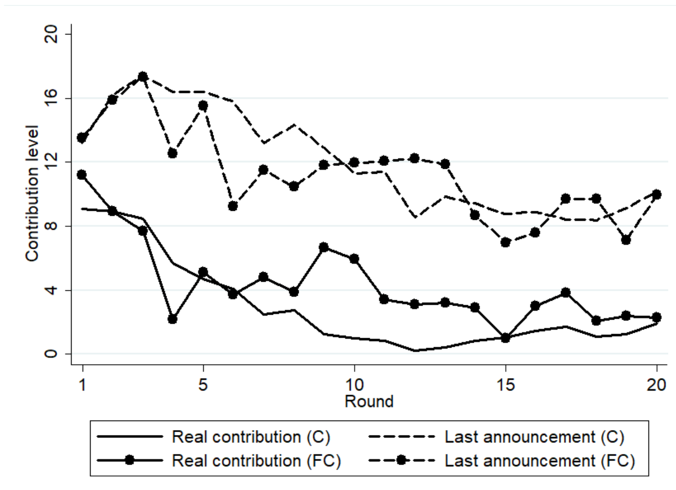

Figure 2: Intentions vs. contributions in treatments *C* and *FC*. The intentions and contributions levels are calculated at four-player game level.

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

Result 3. *In C, the contribution converges to almost zero over time. Though subjects send high intended actions, they tend to deviate to near zero in their actual contribution.*

5.2.3 Final commitment

In treatment *FC*, subjects start by contributing more than half of their points to the public good, but contributions also decline over time.

Next, we examine the behavior pattern in the *FC* treatment. Recall that Figure 2 shows the subjects' last announcements and their actual contribution in treatments *C* and *FC*.

In treatment *C*, the subjects' last intended action is defined unambiguously as their last announcement in the real-time stage. However, since subjects' last announcements in treatment *FC* determine their actual contribution, we instead choose their second to last announcements as their last intended actions because their second last announcements are the latest announcements that are *payoff-irrelevant*. Moreover, in order to qualify the last updated announcement as a deviation from the previous announcements, it must happen at the very end of the one-minute stage. We employ the following empirical criteria for the latest *payoff-irrelevant* announcement: it is the second last announcement if the last revision of announcement is made within the last 3 seconds of the 60 seconds; otherwise, it is the last announcement.[18]

Similar to treatment *C*, we can see from Figure 2 that subjects tend to deviate downward at their last revisions of announcements. That is, even when subjects can monitor each other in real time , they still deviate to near zero contribution in the very end of the one-minute stage. We perform a test to see if the differences between the actual choices and the last announcements are different between *C* and *FC* (difference in difference), the Mann-Whitney test shows that they are significantly different ($p = 0.025$, n=12).[19]

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 achieve efficient coordination in a minimum effort game. However, our game differs from the minimum effort game in that, in ours, the 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 contribution in a public goods game.

Result 4. *In FC, contribution declines over time. Though subjects start by sending high intended actions, they deviate to almost zero contribution by the end of the minute.*

[18]This criteria can be understood by comparing the time distribution of last announcements in treatment *C* and *FC* (see Figure 7 in Appendix C): Compared to treatment *C*, in treatment *FC*, it happens much more often that the last update takes place in the final 3 seconds (48.54%). Therefore, we consider such last-second updates 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 instead treat the last announcements as both intended actions and real contributions.

[19]The average difference between the last announcement and the actual contribution is 9.05 in treatment *C* 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 (Mann-Whitney tests, $p = 0.522$, $p = 0.522$).

5.2.4 Incremental commitment

In treatment *IC*, we can see from Figure 1 and Table 2 that contributions no longer decline over rounds. In contrast, contributions in treatment *IC* fluctuate around half of the maximum level over the twenty rounds.

Next, we examine the behavior pattern in treatment *IC* more closely. Figure 3 shows the average contribution of players who contribute the lowest, second lowest, and second highest and the highest in each game of the four players. First, at the aggregate level, we can see that contributions within a group are highly correlated, indicating that subjects' decisions are influenced by the choices of others in the game.[20] Moreover, there exists a significant gap between the highest and lowest contribution within each game, and such a gap does not seem to diminish over time. The average difference between the highest and lowest contribution is about 6 (30% of the total points), suggesting that significant inequality is present between players.

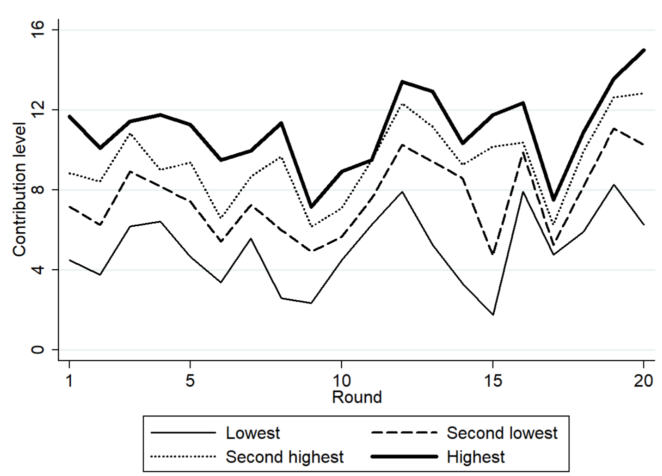

Figure 3: Average contribution level of each player. The average contribution levels of the players are calculated at the four-player game level.

Our results for *IC* treatment 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.

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

Result 5. *In IC, the contribution is significantly higher than zero, and does not exhibit an increasing or declining pattern over time. Within each game, non-trivial differences between the highest and lowest contributions persist over time.*

5.2.5 Incremental commitment with a clock

In treatment *ICC*, contributions increase and reach a high level over time. The Nash equilibrium prediction is that the contribution level equals zero. The ϵ-equilibrium with standard preference (or weak inequality-aversion) predicts that exactly one player opts out at $t = 0$, and the other three players opt out immediately if a second player opts out. Finally, the ϵ-equilibrium with strong inequality-aversion predicts that once one player opts out, the other three players follow immediately. Our results clearly reject the Nash equilibrium prediction and support predictions by ϵ-equilibrium.

To investigate whether our results are consistent with standard preference (weak inequality-aversion) or preference with strong inequality-aversion, we examine the opting out time pattern in all groups. First, Figure 4 shows the average opting out time of the player who opts out the first, the second, the third, and the fourth, respectively. We can see that, once one of the players opts out, the other three players follow almost immediately. The average time lag between each two successive quitters is within 2 seconds (1.8 seconds between quitters 1 and 2, 0.5 seconds between quitters 2 and 3, and 1.8 seconds between quitters 3 and 4). Over time, the first quitter opts out later and later, which can be explained by learning from past outcomes.

Next, we examine the proportion of the game results corresponding to the three different theoretical predictions mentioned above. Considering the limitations of subjects' attention and reaction time, we say that a subject "opts out at the beginning of the game" if one opts out in the first second, instead of using the very restrictive theoretical prediction $t = 0$. Further, we define an opting out choice as an "immediate reaction" to the previous opting out choice in the group if the time lag between them is not larger than 2 seconds.[21] According to these two criteria, we further divide all the games in this treatment into the following four categories.

[21] We use two seconds for the reaction interval, because subjects need to first observe another player's action and react to it, which presumably takes longer than just opting out in the beginning of the time.

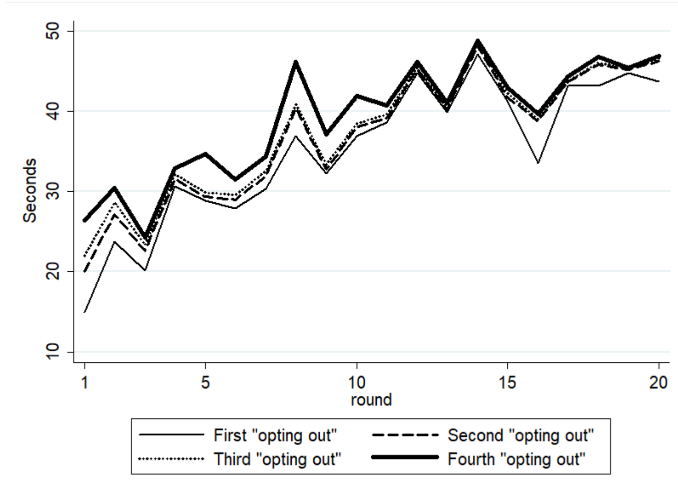

Figure 4: Average opting out time of each player in *ICC*. The average opting out time are calculated at the four-player game level.

(i) *Nash equilibrium prediction*: All subjects in the same group opt out within the first second.
(ii) *ϵ-equilibrium prediction with standard preference or weak inequality-aversion*: One subject opts out within the first second, the second quitter opts out after the first second, and the time lag between any two successive "opting out" choices of the last three quitters are no more than 2 seconds.
(iii) *ϵ-equilibrium prediction with strong inequality-aversion*: All four subjects opt out after the first second, and the time lag between any two successive "opting out" choices are no more than 2 seconds.
(iv) *others*: Cases cannot be classified by the other three categories.

Note that the above categories are determined carefully so that they are mutually exclusive. However, it is worth noting that the cases classified as the Nash equilibrium predictions can always be supported by the ϵ-equilibrium prediction. Therefore, types (ii) and (iii) cannot be supported by Nash equilibrium. We summarize the four behavioral categories in Table 3. We can see that the ϵ-equilibrium prediction with strong inequality-aversion has the strongest prediction power, which accounts for 59.6% of the total cases. This is followed by ϵ-equilibrium prediction with standard preferences (or weak inequality-aversion), which accounts for 8.8% of total cases. Only 0.8% of the total cases are in line with the Nash equilibrium prediction. Overall, the results indicate that there is strong inequality aversion among most of the players, which causes a quick breakdown of contributions once one player opts out.

Table 3: Categories of behavior pattern in treatment *ICC*

Category	Proportion (%)	Quitting time first player	Quitting time other players	Contribution
i	0.8	0.3	0.9	0.3
ii	8.8	0.6	8.2	2.1
iii	59.6	50.1	50.9	16.9
iv	30.8	16.8	21.9	6.9

Notes: The second column shows the proportion (in percentages) of each category, the third column shows the average quitting time of the first quitter, the fourth column shows the average quitting time of the other players, and the last column shows the average contribution.

Finally, recall that the ϵ-equilibria yields multiple equilibrium predictions (see Section 3.4), one remaining question is which equilibria occur more often than others. In other words, if the other subjects follow the first quit to opt out within a short time, for the first quitter, it is an equilibrium to quit at any time. Therefore, the first opting out time is very essential for the overall contribution level. Note that for both equilibrium predictions with strong inequality aversion or weak inequality aversion, the equilibrium selection could be approximately identified by the average opting out time of the last three quitters. Figure 5 shows the cumulative distribution of ϵ-equilibrium, based on all the cases classified by category (i), (ii), and (iii). We can see that in nearly 50% of the cases the last three quitters in the group "stay in" until the end of the one-minute interval. This indicates that the most prevalent ϵ-equilibrium is the one in which players use the near-dominant strategy, that is, they stay in until a sufficient number of players opt out.

Result 6. *In ICC, the contribution increases over time. In most cases, once one player opts out, the other three follow quickly. This result is mostly consistent with the theoretical predictions of ϵ-equilibrium with sufficiently strong inequality-aversion.*

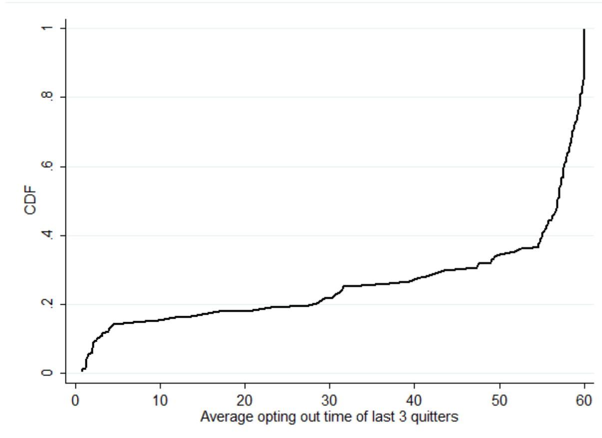

Figure 5: Distribution of ϵ-equilibria in *ICC*. ϵ-equilibria behavioral types are represented by the average opting out time of the last 3 quitters.

5.3 Learning

According to Figure 1, there seems to be a learning pattern for all the treatments. To check if there is a learning effect, we perform a sign-rank test in each treatment, comparing the contribution levels in the first ten rounds and the last ten rounds. The sign-rank tests show that, in treatments *B*, *C*, *FC*, and *ICC*, the contribution levels differ significantly in the first ten and the last ten rounds. In treatments *B*, *C*, 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 twenty rounds. On the other hand, in the *IC* treatment, we do not find a significant difference in the contribution level between the first ten and the last ten rounds, indicating that over rounds, it seems to be more difficult for subjects in *IC* to figure out a clear way of acting.

Table 4: Contribution levels in rounds 1-10 vs. rounds 11-20.

Treatments	Rounds 1-10	Rounds 11-20	Sign-rank test
B	4.28	0.85	$p = 0.027$
C	4.84	1.08	$p = 0.027$
FC	6.01	2.72	$p = 0.027$
IC	7.47	9.11	$p = 0.345$
ICC	10.30	14.46	$p = 0.027$

Result 7. *The evidence of learning is clear in treatments B, C, FC, and ICC, but not in treatment IC. Over time, contributions decrease in B, C, and FC, but increase in ICC.*

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: cheap talk, 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.

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 1.
Proof of Nash equilibrium outcome in Incremental Commitment. Consider an outcome in which at least one player contributes a positive amount to the public good. Then, there must be one player (or more than one player) who makes the very last update to increase his contribution in the one minute stage. For such a player, he can be better off by not making the last update, so that he can earn a profit. Note that, since no players make any changes after him, he can clearly be better off by doing so. Therefore, any outcome in which at least one player makes a positive amount if not a Nash equilibrium outcome. The only Nash equilibrium outcome is the one in which everyone contributes zero to the public good.
Proof of Nash equilibrium outcome in Incremental Commitment with a Clock. Consider an outcome in which at least one player contributes a positive amount to the public good. This means that such a player does not stop his contribution from increasing at $t = 0$. Then there must exists a player (or more than one player) who is the last one to stop. For such a player, he can be better off by stopping a bit earlier (e.g. by τ, the reaction time of other players). Since he is the last player who stops, such deviation will not affect the strategies of any other players in the game. Therefore, an outcome in which at least one player stops at $t > 0$ can not survive as a Nash equilibrium outcome. The only Nash equilibrium outcome is the one in which everyone contributes zero to the public good.

Proof of Proposition 2. First, we prove that for $\epsilon \geq 24\tau$, after one player opts out, it is a near dominant strategy for the other three players to stay unless another player opts out.

For player i with $i \neq 1$, suppose that the other two remaining player's strategy is to opt out at $t \geq s_j$ and $t \geq s_k$ with $s_j \leq s_k$ (or when another player opts out), then player i's optimal strategy is to opt out just a little earlier 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 by leaving a little earlier than player j. We denote the payoff by opting out at $s_j - \tau$ as $u(s_j - \tau)$. Compared to this maximal payoff, the strategy to leave only when a second player opts out is equivalent to leaving at $s_j + \tau$. Therefore, the payoff difference is presented in the equation below.

$$
\begin{aligned}
&max\{u(s_j-\tau)-u(s_j+\tau)\}\\
&=\{20s_j*0.4*2+20(s_j-\tau)*0.4-20(s_j-\tau)\}\\
&-\{20s_j*0.4*2+20(s_j+\tau)*0.4-20(s_j+\tau)\}\\
&=24\tau
\end{aligned}
$$

The maximal value of the above equation is achieved when $s_j = s_k$, as only in this case player i does not make player j or player k to leave earlier by opting out at $s_j - \tau$.

Therefore, if $\epsilon \geq 24\tau$, staying in the contributing phase unless a second player opts out is always in the ϵ-best response set, no matter when the other players plan to opt out: such a strategy is a near dominant strategy. Given that the remaining three players will use such a near dominant strategy after one player opts out, it is an optimal strategy for the first player to opt out at $t = 0$, he achieves highest payoff this way. No player wishes to deviate, this is an ϵ-equilibrium.

Second, consider the strategy profile $s_1 = 0$ and $s_2 = s_3 = s_4 = \tilde{s}$. For players 2, 3 or 4, the maximal gain is achieved by deviating to $\tilde{s} - \tau$, as this way she can opt out earlier to gain a bit more payoff, without making the other players opting out earlier. By deviating to $\tilde{s} - \tau$, one gains 20τ in her private account, and loses $0.4 * 20\tau$ in her public account: one has a maximal net gain of 12τ. Therefore, if $\epsilon \geq 12\tau$, choosing the same $\tilde{s}$ as the other two players is one of the best strategies. The rest of the proof is the same as the first set of equilibria. In sum, the strategy profile $s_1 = 0$ and $s_2 = s_3 = s_4 = \tilde{s}$ for $o \leq \tilde{s} \leq 1$is an ϵ-equilibrium if $\epsilon \geq 12\tau$.

Proof of Proposition 3. First, we prove that for $\epsilon \geq 24\tau + \frac{20\alpha\tau}{3}$, it is a near dominant strategy for all the players to stay unless one player opts out.

For player i, suppose that the other three player's strategy is to opt out at $t \geq s_j$, $t \geq s_k$ and $t \geq s_q$ with $s_j \leq s_k \leq s_q$ (or when another player opts out), then player i's optimal strategy is to opt out just a little earlier than player j 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 by leaving a little earlier than player j. We denote the payoff by opting out at $s_j - \tau$ as $u(s_j - \tau)$. Compared to this maximal payoff, the strategy to leave only when one player opts out is equivalent to leaving at $s_j + \tau$. Therefore, the payoff difference is presented in the equation below.

$$
\begin{aligned}
&max\{u(s_j-\tau)-u(s_j+\tau)\}\\
&=\{20s_j*0.4*2+20(s_j-\tau)*0.4-20(s_j-\tau)\}\\
&-\{20s_j*0.4*2+20(s_j+\tau)*0.4-20(s_j+\tau)-20\frac{\alpha}{3}*1\}\\
&=24\tau+\frac{20\alpha\tau}{3}
\end{aligned}
$$

The maximal value of the above equation is achieved when $s_j = s_k = s_q$, as only in this case player i does not make player j or player k to leave earlier by opting out at $s_j - \tau$.

Therefore, if $\epsilon \geq 24\tau + \frac{20\alpha\tau}{3}$, then staying in the contributing phase unless one player opts out is always in the ϵ-best response set, no matter when the other players plan to opt out. Therefore, such a strategy is a near dominant strategy. When each player uses such a near dominant strategy, it is an ϵ-equilibrium.

Second, consider the strategy profile $s_1 = s_2 = s_3 = s_4 = \tilde{s}$ with $0 \leq \tilde{s} \leq 1$. For any player, the maximal gain is achieved by deviating to $\tilde{s} - \tau$, as this way she can opt out earlier to gain a bit more payoff, without making the other players opting out earlier. By deviating to $\tilde{s} - \tau$, one gains 20τ in her private account, and loses $0.4 * 20\tau$ in her public account: one has a maximal net gain of 12τ. Note that this part is exactly the same as the proof of Proposition 2, because deviating to opting out earlier only allows the player to earn more instead of less than others, therefore this deviation does not trigger inequality aversion. In sum, the strategy profile $s_1 = s_2 = s_3 = s_4 = \tilde{s}$ for $0 \leq \tilde{s} \leq 1$ is an ϵ-equilibrium if $\epsilon \geq 12\tau$.

Appendix B: Experimental instructions

In this appendix, we provide the experimental instructions 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 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. At the end of the game, you can see the total points in the public account and your earnings in the game.

Part II (All treatments)

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.

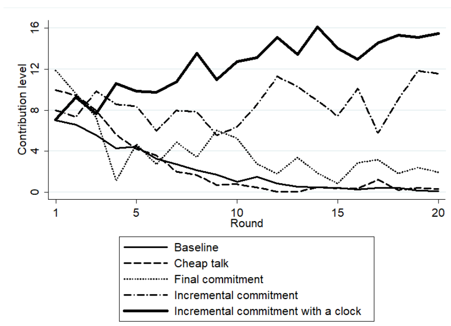
In each round, the identity of participants in the group will be represented by A, B, C,

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.

Appendix C: Supplemental figures and tables

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



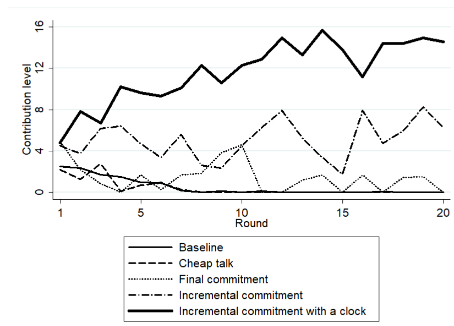
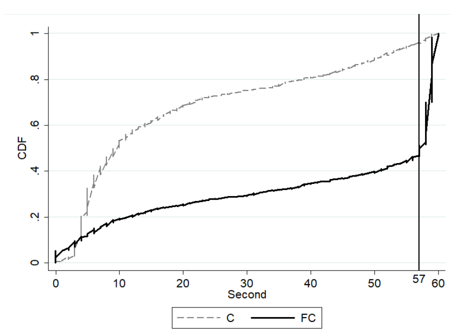


Figure 6: Median (left) and minimum (right) contribution over rounds.



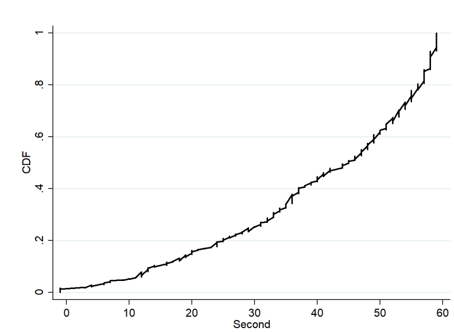


Figure 7: Time distribution of each player's last announcement in *C* and *FC* (left), and time distribution of each four-player game's last announcement in *IC* (right).