Real-time Monitoring in a Public Goods Game*

Simin He† and Xun Zhu‡

July 28, 2020

Abstract

Public goods problems are prevalent in economics and are challenging to resolve. In this study, we investigate a novel continuous-time incremental commitment mechanism. Within a fixed time period, people can choose when to stop their contributions from increasing exogenously, and their actions are observed by others. We show both theoretically and experimentally that it is a very effective mechanism to help improve contribution. Moreover, we compare this mechanism with other mechanisms under similar real-time environment, and find that the mechanism becomes ineffective when the incremental commitment feature is absent. Our findings can be potentially extended to other social dilemma situations.

Keywords: Public goods, continuous time, incremental commitment, cheap talk.
JEL codes: C72, C92, D82.

---

*The authors sincerely thank Syngjoo Choi, Bin Miao, Lan Yao, and the participants of the Nottingham CeDEx China Workshop on Behavioral and Experimental Economics and the Virtual East Asia Experimental and Behavioral Experimental Seminar Series for their helpful comments.

†School of Economics, Shanghai University of Finance and Economics, 111 Wuchuan Rd, 200433 Shanghai, China. E-mail: he.simin@mail.shufe.edu.cn.

‡School of Management, Fudan University, 670 Guoshun Rd, 200433 Shanghai, China. E-mail: zhuxun_0609@163.sufe.edu.cn.

1 Introduction

Public goods games are very prevalent in economics, and their desired outcome requires people to contribute to a public pool efficiently. For example, building a dam that benefits people living around it requires everyone to contribute; fighting global warming problem requires all countries to reduce their carbon emissions. Yet, it is a challenging problem, because not contributing to the public good is in everyone's private interest and is supported by 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 show that some mechanisms can help to 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 incremental commitment mechanism in continuous time.

The incremental commitment mechanism works as follows: within a fixed period of time, the contribution of each player is monotonically increased over time by an exogenous institution, and players choose when to stop their contribution from increasing. Once 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 goods game: the earlier one stops, the less she contributes.

Such a mechanism is worth investigating for both theoretical and empirical reasons. Theoretically, the incremental commitment setup enables players who are conditional cooperators to contribute only if others contribute as well. Moreover, under the continuous-time setup, it is intuitive to conjecture that players may forego a small amount of loss if they choose to stop only after observing others' stopping actions, which is consistent with the intuition of ϵ-equilibrium. Together, this mechanism potentially induces high contribution among players. Empirically, there are many economic situations in which we can implement such a mechanism. For example, if countries want to decrease each other's nuclear warhead, it maybe easier to achieve so if they decrease their own warhead bit by bit at the same time. Or, if a few neighbors are to donate to a public good, they may

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

[2]There are many underling reasons for why people can reach high contribution in public goods game, 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 reversed direction, in that there is a clock and each person can choose when to stop increasing (decreasing) one's own contribution (bidding price).

achieve so by slowly increasing one's own donation, conditioning on observing incremental donation of others.

In this study, we investigate whether such an incremental commitment mechanism is effective in a four-player linear public goods game with a marginal public-good contribution rate of 0.4. In order to understand if real-time (or so continuous-time) monitoring itself is sufficient to boost contribution, we implement two other mechanisms under real-time setting. The first is a cheap talk setup, in which players have one minute to send announcements of their intended actions before the game. During this minute, they can send announcements as many times as they want to, and the latest announcement is always perfectly observed by the entire group. After this minute, players choose their contributions in the game, and their choices are not constrained by their previous announcements. The second setup is called cheap talk with final commitment. This setup is very similar to the cheap talk one, and the only difference is that players' last announcements in the one minute become their actual contribution in the game. Finally, the incremental mechanism also has a one-minute phase, during which contribution levels exogenously increase over time, and players can choose when to stop increasing their contributions. The commitment level is lowest in the cheap talk setup, and highest in the incremental commitment setup. And by comparing all these setups, we can learn the essential factors needed to induce contribution under real-time monitoring. Finally, we also include the baseline game without any mechanisms as a control setup.

Theoretically, Nash equilibrium predictions are the same for all these four setups. That is, players contribute zero to the public goods. However, since the decision time is continuous in the incremental commitment setup, we apply ϵ-equilibrium to make the theoretical predictions for this mechanism. We find that, with standard preferences, in equilibrium one player stops contributing at the very beginning of the clock, whereas the other three players have a near dominant strategy to continue contributing unless someone else stops. The intuition is that, by keeping contributing when there are still three players, the total return rate is 1.2 (0.4×3); however, if one stops contributing, he 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 goods.[5] In summary, ϵ-equilibrium predicts that it is possible to sustain high contribution level in the incremental commitment setup,

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

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 the four setups to the laboratory as four 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. Note that, random matching is a more challenging setup compared to fixed matching, because players cannot build reputation. Arguably, it is more difficult to achieve high contribution level under random-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 details of each treatment are exactly the same as the setup described before.

The experimental results show that in the baseline treatment, contributions converge to zero over time. In the cheap talk treatment, subjects tend to make announcements of high contributions, but then deviate from their announcements in the game; contributions also converge to zero over time. In the cheap talk with final commitment treatment, subjects start by making announcements of high contributions, but tend to announce a much lower level by the end of the one minute, yielding a similar pattern to the other two treatments. Finally, in the incremental commitment treatment, though contribution levels are not different from the other three treatments in the first round, they increase over time and reach about 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 another group member stops. Note that the experimental results are not trivial, because there are many other equilibria in which contributions are low. This result suggests that this mechanism and its underlying near dominant strategy is behaviorally obvious for the subjects. In sum, these experimental results indicate that, under real-time monitoring, cheap talk alone, with or without final commitment, is not sufficient to boost contribution. Incremental commitment, however, demands a higher level of commitment and is necessary to induce contribution.

[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 have an important role in sustaining cooperation with punishments.

The paper is organized as follows. Section 2 discusses the related literature. Section 3 presents the basic setup and the theoretical predictions. Section 4 introduces the experimental design and procedures. Section 5 provides the results. Section 6 concludes.

2 Related literature

There are a large amount of experimental studies on public-goods games; see Ledyard (1995), Chaudhuri (2011) for two critical surveys of public goods experiments. There are three established facts in these studies. First, subjects contribute more than the theoretical prediction in one-shot games or at the beginning of the repeated games. Second, the contributions decline steadily over time to the Nash equilibrium predictions under both fixed partnership 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-partnership (e.g., Fehr and Gächter 2000, Masclet et al. 2003, Walker and Halloran 2004, Gunnthorsdottir et al. 2007, Nikiforakis 2008). 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). Our cheap talk treatment falls into the second category, 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 a one-minute pregame stage. This allows us to tease out the effect of cheap talk under real-time setting, compared to the incremental commitment treatment.

There are a handful of experimental papers with real-time monitoring but in different games compared to ours. Deck and Nikiforakis (2012) study how real-time monitoring affects behaviors in a minimum-effort coordination games. In a one-minute pregame phase, subjects can choose their actions and change it freely at any time; these actions can be either perfectly or imperfectly observed by the other group members. Our cheap talk with final commitment treatment is similar to their perfect monitoring treatment. They find that when subjects can perfectly monitor 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 Pareto optimal equilibrium. Moreover, they further test a cheap talk mechanism, which only differs in that the last actions in the real-time stage are nonbinding. They find that such a cheap talk mechanism under real-time monitoring is not as effective as the mechanism with commitment, but is somewhat effective compared to the baseline. These two studies show that, real-time monitoring is very effective in minimum-effort games, especially when the actions in the monitoring stage are binding. This raises questions on whether such mechanisms are sufficient to improve contribution in public goods games. The challenge is that, in public goods games the Pareto efficient outcome is not a Nash equilibrium. Therefore, it is arguably more difficult to achieve such an outcome in public goods games compared to minimum effort games.

Our 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 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 continuous game found in prisoner dilemma game is muted in the public goods game. But when adding communication in the continuous game setting, subjects contribute at 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 2 to 4; second, the strategy space changes from binary to the entire contribution interval. Both differences potentially make it harder for players to sustain cooperation.[7] Compared to the continuous public goods game in Oprea et al. (2014), our incremental commitment mechanism also allows a continuous time setup, but is different in two fundamental ways: first, our game is not a continuous game, because the 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 revise their contribution to a lower level over time.

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

The most relevant work to ours are experimental studies that implement public goods games with real-time monitoring. Dorsey (1992) is the first paper that introduces real-time monitoring in a public goods game. In a one-minute stage, subjects in the irreversible treatment 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 fail to do so. Kurzban et al. (2001) replicate the design of Dorsey (1992) and study the effect of different information disclosure. They provide information of either the highest contribution in a group or the lowest contribution. They find that only the combination of providing lowest contribution and the irreversible setting can eliminate the decay trend of contribution. Later, Tan et al. (2015) further extend the study of Dorsey (1992) by introducing the opposite version of the irreversible condition, in which each subject's contribution is set at the maximal contribution in the start and subjects can only decrease their contribution over time. 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, both with and without a positive completion benefit, compared to a static one.[8] Our incremental commitment mechanism is similar to these studies in that subjects can only increase their contribution, and therefore shares the spirit of gradualism in contribution. But our mechanism differ from them 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 subjects have to make. Second, our mechanism works in continuous time, and by applying ϵ-equilibrium in such a continuous-time setup, high contribution levels can always be supported regardless of the behavioral types of the players.[9]

Finally, the theoretical framework of our incremental commitment mechanism applies the concept of ϵ-equilibrium, which has been studied in theoretical papers such as Radner (1986), Simon and Stinchcombe (1989), and Bergin and MacLeod (1993).[10]

[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.

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

3 Theoretical background

In this section, we investigate the impact of each mechanism in a four-player 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 Baseline

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

Proposition 1 (Baseline equilibrium). *In the baseline game, the Nash equilibrium strategy of each player i is $g_i = 0$.*

3.2 Cheap talk

In the cheap talk game, 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, there is a unique Nash equilibrium, in which all players choose zero contribution.

Proposition 2 (Cheap talk equilibrium). *In the cheap talk game, the Nash equilibrium strategy of each player i is $g_i = 0$.*

3.3 Cheap talk with final commitment

In the cheap talk game with final commitment, players send their intended actions in the one-minute phase, and their last intended action becomes their final contribution level. We use m_i to represent the intended actions sent by player i, and m_i is a function of time. Suppose that all the players have a reaction time $\tau > 0$, which denotes the minimal time it takes a player to react after seeing a change in others' intended actions. Let $t \in [0, 1]$ denote the time within the one-minute interval. We argue that, at $t = 1 - \tau$ or later, it is a dominant strategy to send an intended action of zero contribution ($m_i = 0$). The reason is the following: no matter what the others' strategies are, at $t = 1 - \tau$ (or later) the remaining time is too short for others to react accordingly. Therefore, choosing zero contribution at this time is a dominant strategy, no matter what strategies are used by the other players. On the other hand, it does not matter what intended actions are sent before $t = 1 - \tau$. Therefore, in this game, in equilibrium all players choose zero contribution by the end of the one-minute phase.

Proposition 3 (Cheap talk with final commitment equilibrium)**.** *In the cheap talk game with final commitment, in Nash equilibrium, the strategy of each player i has the following form:* $m_i \in [0,1]$ *when* $t < 1 - \tau$, $m_i = 0$ *when* $t \geq 1 - \tau$.

The results in Proposition 3 is theoretically equivalent to $g_i = 0$ for all players in normal-form game G. That is, in equilibrium players contribute zero to the public goods.

3.4 Incremental commitment

In the public goods game with incremental commitment, players choose when to opt out from increasing their contribution level. Again, let $t \in [0,1]$ denote the time within the one-minute interval. Then a player's strategy can be represented by his or her opting out time s_i, with $s_i \in [0,1]$. Since each player can perfectly observe other players' opting out time (given it's already happened), we argue that a player's behavioral strategy depends both on the time t, as well as other players' strategies. We can consider such a strategy as a cutoff strategy, that is, player i will opt out from the contributing phase when $t \geq s_i$ or when sufficient number of players have already opted out, and stay in otherwise.

By backward induction, the last player who opts out from the contributing phase should opts out immediately after observing the third player opting out, since contributing to the public goods yields a lower return than keeping to one's private account. The second last player should opt out immediately after observing the second player opting out, as the return of two remaining player's contributing to public good is still worse than keeping to one's private account. For the second player, his optimal opting out time is just a little bit ahead of the third player planned opting out time, as this way he gains some profit without affecting the third player. By this logic, the third player also wishes to opt out just a little bit ahead of the second player. After all, the Nash equilibrium is that all the four players opt out at the very beginning ($s_i = 0$ for all players).

Proposition 4 (Incremental commitment equilibrium)**.** *In the incremental commitment game, the Nash equilibrium strategy of each player i is:* $s_i = 0$.

The results in Proposition 4 is theoretically equivalent to $g_i = 0$ for all players in normal-form game G. That is, in equilibrium players contribute zero to the public goods.

3.4.1 ϵ-equilibrium

One important feature of the incremental commitment mechanism is that players observe each other's strategies in a real-time manner, and can adjust their strategies according to other players' strategies very quickly. For example, if player i opts out immediately after observing that player j just opts out (with a reaction time τ), player i's payoff is just a little bit lower than player j, given that τ is very small. This raises the question of whether ϵ-equilibrium is a more appropriate solution concept.

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 $B_{i,\epsilon}(P^*_{-i})$.*

Applying the ϵ-equilibrium solution concept to our incremental commitment mechanism yields interesting predictions. This is because when there are three players still in the contributing phase, as long as these three players all opt out at the same time, a player can only gain a small payoff by deviating to opting out a little bit earlier. If he deviates to opt out much earlier than the other two players, they will opt out immediately after and therefore result in a worse payoff. However, it is not possible for all the four players to stay in the contributing phase, as when exactly one player opts out, the other three still find it beneficial to stay in, therefore the fourth player's dominant strategy is to opt out at $t = 0$ and free rides on the other three players. For the other three players, if they opt out at the same time or with very little time lag, it could become an ϵ-equilibrium, as long as ϵ is sufficiently big. In fact, without knowing the cutoff opting out time of the other two players, it is a near dominant strategy for each of the three players to stay in the contributing phase, unless someone else opts out first. We first provide the definition of "near dominant strategy" below.

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.*

Using the concept of near dominant strategy, we characterize the $\epsilon-$equilibria in the public goods game with incremental commitment.

Proposition 5 (Incremental commitment ϵ-equilibria)**.** *In the incremental commitment game, for $\epsilon \geq 24\tau$, there exists an ϵ-equilibrium in which one player (call him player 1) has $s_1 = 0$, and the other three players has the same cutoff strategy $K(1)$, that is, they "Opt out" when $n(-i) \geq 2$, "Stay in" otherwise. 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 $t \geq \tilde{s}$ ($0 \leq \tilde{s} < 1$), and "Stay in" otherwise. $n(-i)$ is the number of opted out players other than oneself.*

In the first set of equilibria characterized in Proposition 5, exactly one player opts out at $t = 0$, and the other three players use a near dominant strategy, in which they stay in unless a second player opts out, which means that in their cutoff strategy $k(s_i)$, we have $s_2 = s_3 = s_4 = 1$. In this equilibrium, three players contribute fully to the public goods, and one player free rides on them.

In the second set of equilibria characterized in Proposition 5, again exactly one player opts out at $t = 0$, and the other three players use an identical cutoff strategy. 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 very small time lag, it can become an equilibrium. In this proposition, we only characterize the equilibria in which the three players use the same strategy, either the near dominant strategy $s_2 = s_3 = s_4 = 1$, or $s_2 = s_3 = s_4 = \tilde{s}$ for $0 \leq \tilde{s} < 1$.

3.4.2 Inequality aversion

In the above theoretical analysis, we consider only standard preferences. That is, player only care for their monetary payoff, and do not care for other factors such as inequality. In the equilibrium characterized in Proposition 5, there is a strong asymmetry between the player who opts out at $t = 0$ and the other three players who opt out at $t = 1$. In this equilibrium, one player free rides on the other three players. Current empirical evidence on inequality aversion suggest that it is challenging for such asymmetric equilibrium 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, and sacrifice their potential monetary payoff to reach a more fair result.

In this section, we consider the theoretical predictions if players are (sufficiently) inequality averse. We use the utility function from Fehr and Schmidt (1999) as follows.

We assume that all the players have the same inequality averse level α, which captures how one dislikes that others receiver a higher monetary payoff than himself.[11]

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

Consider the equilibrium characterized in Proposition 5. For what values of α will this equilibrium break down? After the first player, the free rider, opts out from the contributing phase immediately, the remaining players face a trade-off by keep increasing their contributing level: a higher contributing level by the three players increases their monetary payoffs effectively, but also enlarges the payoff difference between them and the free rider. The rate of the former is 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 receives extra payoff from his own private account). The sum of the marginal gain by staying in is presented in the equation below:

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

And if one deviates to opting out, he will contribute his endowment to his private account at the rate of 1, which is presented in the equation below:

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

The equilibrium in Proposition 5 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 5 break down. This suggests that when one player opts out from the contributing phase, all the other three players will also opt out soon (the exact time depends on the value of ϵ). As a result, it is a near dominant strategy for all the players to opt out at $t = 1$ unless someone else opts out earlier. We therefore characterize the following equilibrium with sufficiently strong inequality aversion.

[11] Note that in Fehr and Schmidt (1999), they also consider the dis-utility if oneself receives a higher monetary payoff than others. But 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 of inequality aversion.

Proposition 6 (Incremental commitment ϵ-equilibria with inequality aversion). *In the incremental commitment game with players that are sufficiently inequality averse ($\alpha > 0.6$), for $\epsilon \geq 24\tau + \frac{20\alpha\tau}{3}$, there exists an ϵ-equilibrium in which all players use the same cutoff strategy $K(1)$, that is, "Opt out" when $n(-i) \geq 1$ and "Stay in" otherwise. 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 $t \geq \tilde{s}$ ($0 \leq \tilde{s} < 1$), and "Stay in" otherwise. $n(-i)$ is the number of opted out players other than oneself.*

In the first set of equilibria characterized in Proposition 6, all players use a near dominant strategy, in which they stay in unless one player opts out, which means that in their cutoff strategy $k(s_i)$, we have $s_1 = s_2 = s_3 = s_4 = 1$; or, in other words, theoretically equivalent to $g_1 = g_2 = g_3 = g_4 = 20$. In this equilibrium, all players contribute fully to the public goods.

In the second set of equilibria characterized in Proposition 6, 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 $0 \leq \tilde{s} < 1$. Again, note that as long as the four players use a cutoff with very small time lag, it can become an equilibrium. In this proposition, we only characterize the equilibria in which the four players use the same strategy, hence, the symmetric equilibria.

In summary, our incremental commitment mechanism has the same Nash equilibrium predictions compared to the the baseline game and the other two mechanisms. In all these Nash equilibrium predictions, players contribute zero to the public goods. In contrast, when applying the ϵ-equilibrium solution concept to the incremental commitment mechanism, we find that (at least some) players have a near dominant strategy, in which they keep increasing their contribution to the full extent, unless enough players opt out. With strong inequality aversion, we even find that it is possible for all player to reach full contribution. This is a very promising theoretical result. 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 public goods game with four different mechanisms as described in Section 3, namely the Baseline treatment (B), the Cheap talk treatment (C), the Cheap talk with final commitment treatment (CFC), and the Incremental commitment treatment (IC).

Each subject participates in only one of the treatments. In the experiment, all subjects play the same public good game for 20 rounds.[12] In this game, subjects choose their contribution level between 0 and 20 (any number is allowed). To make the experimental results more comparable to theoretical predictions of the one-shot game, we adopt a random matching protocol in 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 reputation in their matching group because they cannot identify one another.

The four treatments differ in the mechanisms before playing the public goods game. In the Baseline treatment, subjects directly choose their public goods contribution simultaneously. In the Cheap talk treatment, 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 the Baseline, their choices are not constrained by any of their announcements made in the cheap talk stage. The Cheap talk with final commitment treatment only differs from the Cheap talk treatment in that, when the one minute stage ends, each subject's last announcement becomes their actual contribution level in the public goods game. Therefore, compared to the Cheap talk treatment, the last announcement in this treatment serves as a commitment. Finally, in the Incremental treatment, subjects again enter a one-minute stage. In this minute, each subject's contribution level endogenously increases from 0 to 20 in a constant pace. 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, and he can not go back to the game. In all treatments, at the end of each round, subjects receive

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

feedback of the group's total public goods contribution and their payoff in this round. Table 1 summarizes the experimental treatments.

Table 1: Summary of treatments

Treatments	One-minute stage	Choice stage	No. of subjects
B	N/A	nonbinding	24
C	announce freely	nonbinding	48
CFC	announce freely	binding	40
IC	opt out once	binding	48

The goal of the above treatment design is to investigate the effect of "auction-like" mechanism in treatment IC, and to understand whether cheap talk and commitment alone can help achieve the effect of such a mechanism. In order to do this, treatment B serves as the benchmark to see whether contributions converge to zero as theory predicts in this condition. By comparing the contribution levels in treatment C and B, we can tease out the effect of cheap talk. Next, by comparing treatment CFC and treatment C, we can see how final commitment affects contribution. Finally, by comparing treatment IC and treatment CFC, we can observe the net effect of the IC mechanism through incremental commitment rather than final commitment and cheap talk.

At the end of the experiment, we administer a short survey, collecting some background information. 2 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 seven sessions in total, one session for the Baseline treatment, and two for each of the other treatments. Treatments were randomized at the session level. Depending on the number of people showed up at the experiment, 16 or 24 subjects participated per session. In total 160 subjects were recruited, most of whom were undergraduate students from various fields of studies.

The experiment was computerized using z-Tree and was conducted in Chinese.[13] Upon arrival, subjects were randomly assigned a card indicating their table number and were

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

seated in the corresponding cubicle. Before the experiment started, subjects read and signed a consent letter to agree to participate in the experiment. All 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.[14] Average earnings were ¥38 (equivalent to around 5 US dollars), including 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, respectively. We can see from Figure 1 that, the contribution level in treatment IC exhibits an increasing pattern over time, and converges to around 75% of the maximal level. In contrast, contribution levels in treatments B and C have a declining pattern, and converge toward zero over time. Contribution level in treatment CFC is more volatile, but overall also exhibits a declining pattern towards zero. This figure shows that, at a first look, only the incremental commitment mechanism induces subjects to contribute sufficient amount of their endowment to the public good.

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 IC reach 60% of the maximal level, and increase to above 70% of the maximal level in the second half of the experiment. 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 second half. Average contribution level in treatment CFC is slightly higher compared to treatments B and C (about 25% over 20 rounds and 15% in the second half), but still much lower than that in treatment IC.

[14]We used Alipay or Wechat pay, according to the preference of each subject, to pay subjects on site. Subjects confirmed receiving of the payments before leaving the laboratory.

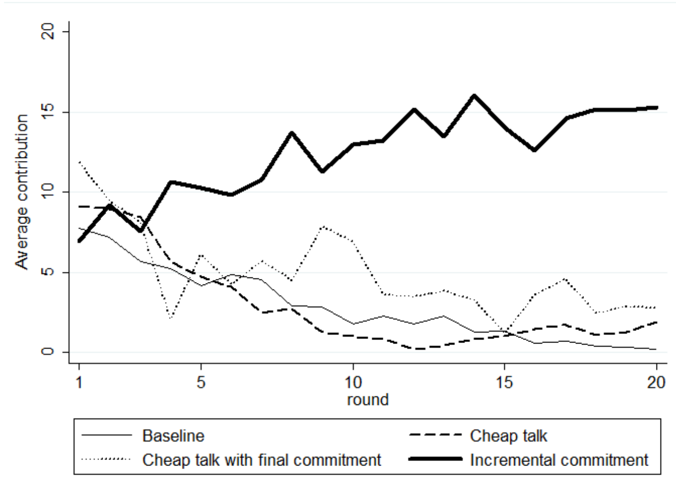

Figure 1: Average contribution over rounds. The average contribution levels are calculated by taking average across matching groups.

Table 2: Average contribution in each treatment

	B	C	CFC	IC
Rounds 1-20	2.90	2.96	4.92	12.38
	(0.91)	(1.05)	(2.99)	(4.58)
Rounds 11-20	1.11	1.08	3.17	14.46
	(0.27)	(0.82)	(3.03)	(5.41)

Notes: Each cell shows the all-round average contribution at 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 IC is significantly higher than in all other three treatments (IC versus B, $p = 0.020$; IC versus C, $p < 0.01$; IC versus CFC, $p = 0.029$), and differences between any pairs of treatment B, C and CFC are insignificant (B versus C, $p = 0.796$; B versus CFC, $p = 0.297$; C versus CFC, $p = 0.273$).

Result 1. *Contributions converge to zero in treatments B, C and CFC, but increases over time and converges to* 75% *of the maximum level in treatment IC. Subjects contribute significantly more in IC than in all the other three treatments.*

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 the Baseline treatment, 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 game with random-matching (see Ledyard 1995, Chaudhuri 2011).

Result 2. *In the Baseline treatment, contribution converges to zero over time.*

5.2.2 Cheap talk

In the Cheap talk treatment, as can be seen from Figure 1 and Table 2, subjects contribute very similar level compared to the Baseline treatment: in the first round, they contribute about 9 out of 20 points to the public good, and their contributions converge to zero over time.

Next, we examine the behavior pattern in the Cheap talk treatment. 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 CFC, 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 though the real-time cheap talk stage induces high intended contributions, it fails to boost actual contribution as subjects don't stick with their intended actions.

This result is consistent with the results in Bochet et al. (2006). Bochet et al. (2006) find that when subjects can indicate their intended actions once before playing the public goods game, both their contribution levels and payoffs are similar to the baseline game. Though subjects can indicate their intended actions for as many times as they want in our setting, it is still insufficient to boost cooperation.

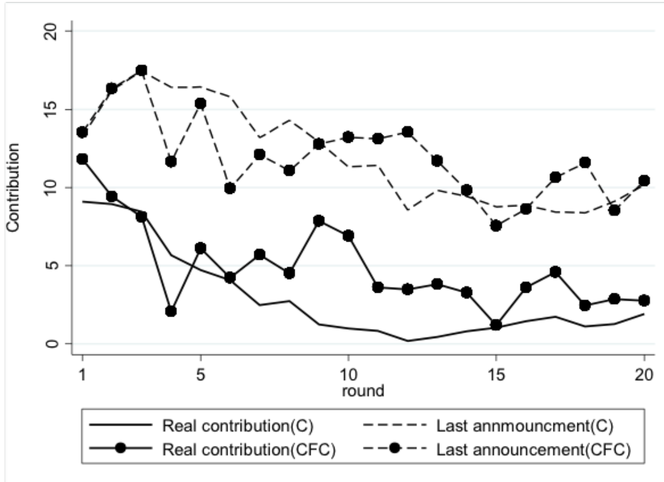

Figure 2: Intentions vs. contribution in treatments C and CFC. The intentions and contributions levels are calculated at four-player game level.

Result 3. *In the Cheap talk treatment, 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 Cheap talk with final commitment

In the Cheap talk with final commitment treatment, subjects start by contributing more than half of their total points to the public good, but their contributions also decline over time. In contrast to treatments B and C, contributions in treatment CFC decline in a more volatile manner.

Next, we examine the behavior pattern in the CFC treatment. Recall that Figure 2 also shows subjects' last announcements and their actual contribution in this treatment. In treatment C, subjects' last intended action is defined unambiguously as their last announcement in the real-time stage. However, since subjects' last announcements in treatment CFC determine their actual contribution, we instead choose their second last announcements as their last intended actions, and their last announcements as their actual actions. This is because their second last announcements are the latest announcements that are *irrelevant* for actual choices. Moreover, in order to qualify the last revision of announcement as a deviation from the previous signals, it has to happen at the very end of the one-minute stage. Therefore we use the following empirical criteria for the latest announcement that is irrelevant for one's actual choice: it is the second last announcement if the last revision of announcement is made within the last 3 seconds of the 60 seconds; it is the last announcement otherwise.[15]

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's action in a real-time setting, 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 in C and CFC (difference in difference), the Mann-Whitney test shows that they are significantly different ($p = 0.029$, n=11).[16]

Our results depart from the findings in 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 our game, high level contribution is not supported by 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 the Cheap talk with final commitment treatment, contribution is higher but close to the theoretical prediction. Though subjects start by sending high intended actions, they deviate to near zero contribution by the end of the minute.*

5.2.4 Incremental commitment

In the Incremental commitment treatment, contributions increase and reach a high level over time. The Nash equilibrium prediction is that contribution level equals to 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

[15]This criteria can be best understood by comparing the time distribution of last announcements in treatment C and CFC (see Figure 6 in Appendix C): While in treatment C the announcements are relative equally distributed across the 60 seconds, in treatment CFC over half (54.78%) of the last announcements take place in the last 3 seconds. This indicates that last minute revisions are common practices in treatment CFC, and can be considered as deviations from one's previous announcements. Therefore, with the presence of revisions in the last 3 seconds, we treat the second last announcements as the intended actions, and the last revision as the actual contribution. For the remaining cases, since last announcements are intact for more than 3 seconds, we instead consider them as both intended actions and real contributions.

[16]The average difference between the last announcement and the actual contribution is 9.05 in treatment C and 7.05 in treatment CFC. Though the differences are significantly different between treatments, neither the average contribution nor the average last announcements are significantly different between these two treatments (Mann-Whitney tests, $p = 0.273$, $p = 0.715$).

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. Firstly, Figure 3 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 interval between each two successive quitters are always 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 the past outcomes.

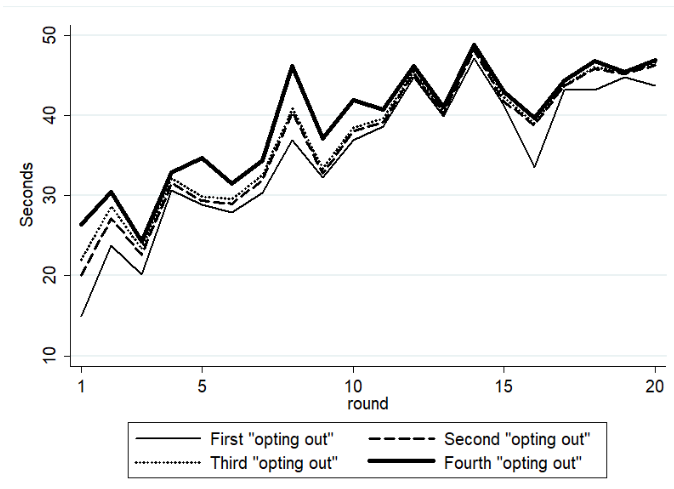

Figure 3: Average opting out time of each player. The average opting out time are calculated at four-player game level.

Next, we examine the proportion of the game results corresponding to three different theoretical predictions mentioned above. Considering the limitation 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 interval between them is not larger than 2 seconds. [17]

[17] 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 one minute.

According to these two criteria, we further divide all the games in this treatment into the following four categories.

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 interval 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 the four subjects opt out after the first second, and the time interval between any two successive "opting out" choices are no more than 2 seconds.

iv (*others*): Cases can not be classified by the other three categories.

Note that the above categories are designed carefully so that they are mutually exclusive. However, it is worth note that the cases classified as the Nash equilibrium predictions can always be supported by the ϵ-equilibrium prediction. Therefore, type ii and iii are the ones that cannot be supported by Nash equilibrium. We summarize the four categories of behavior pattern 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. It is followed by ϵ-equilibrium prediction with standard preference or weak inequality-aversion, which accounts for 8.8% of total cases. Only 0.8% of total cases are in line with the Nash equilibrium prediction. Overall, the results indicate that there is strong inequality aversion among the majority of the players, which causes quick breakdown of contribution once one player opts out.

Table 3: Categories of behavior pattern in treatment IC

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, 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? Or, in other words, as long as the other subjects follow the first quitter 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 4 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 someone else opts out.

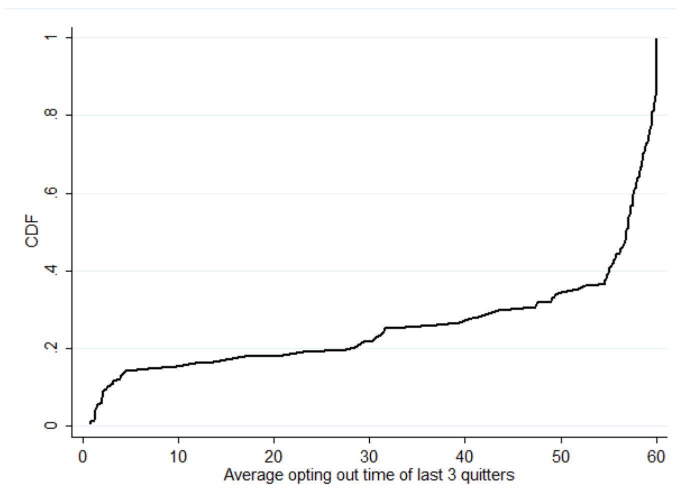

Figure 4: Distribution of ϵ-equilibria. Behaviors that are consistent with the ϵ-equilibria are represented by the average opting out time of the last 3 quitters.

Result 5. *In the Incremental commitment treatment, contribution increases over time. In most cases, once one player opts out, the other three follow quickly. This result is mostly consistent with theoretical predictions of ϵ-equilibrium with sufficiently strong inequality-aversion.*

5.3 Learning

According to Figure 1, there seems to be a learning pattern in all the treatments. In order to check if there is a learning effect, we perform 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 C, CFC and IC, the contribution levels differ significantly in the first ten and the last ten rounds. That is, subjects do learn over time in all the treatments with real-time monitoring. In treatments C and CFC, the mechanism become less effective over time, whereas in treatment IC, it becomes more effective over time. This indicates that the effect of the IC mechanism should be expected to be stronger had subjects played it for more than twenty rounds.

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

Treatments	Rounds 1-10	Rounds 11-20	Sign-rank test
B	4.69	1.11	$p = 0.109$
C	4.84	1.08	$p = 0.027$
CFC	6.67	3.17	$p = 0.043$
IC	10.30	14.46	$p = 0.027$

Result 6. *In treatments C, CFC and IC, there is a clear evidence of learning. Over time, contributions decrease in C and CFC, but increase in IC.*

6 Conclusion

In this study, we propose a real-time incremental commitment mechanism to foster cooperation in public goods games. In order to investigate the essential factors that are effective in boosting cooperation under the real-time setting, we study this mechanism together with three others: a cheap talk mechanism, a cheap talk with final commitment mechanism, and a baseline public goods game. Theoretically, Nash equilibrium gives the same predictions for all these setups; ϵ-equilibrium, in contrast, predicts that it is possible to achieve full cooperation in the incremental commitment setup. Experimentally, we implement these mechanisms under a random-matching protocol, and find that subjects converge to high contribution levels in the incremental commitment treatment, but not in the others. These results are consistent with the ϵ-equilibrium predictions.

This study compares a few real-time monitoring mechanisms in public goods game. When subjects can announce their intended actions freely in a pregame stage, they tend to agree on a relatively high level contribution, but then deviate to the Nash prediction in the game stage. When the last announcements in the pregame stage determine final decisions in the game stage, subjects still choose to deviate to Nash equilibrium by the end of the pregame stage, yielding no higher contribution compared to the baseline or the cheap talk treatments. These results indicate that under real-time monitoring, as long as subjects can deviate to the Nash equilibrium, they may do so unavoidably. However, in the incremental commitment treatment, since the contribution levels are irreversible and are perfectly monitored, it demands a strong commitment, which is both sufficient and necessary to induce high contribution in the public goods game.

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

References

Andreoni, J. (1988). Why free ride? : Strategies and learning in public goods experiments. *Journal of Public Economics*, 37.

Andreoni, J. (1995). Cooperation in public-goods experiments: Kindness or confusion? *American Economic Review*, 85(4):891–904.

Avoyan, A. and Ramos, J. (2020). A road to efficiency through communication and commitment. *Available at SSRN 2777644*.

Bergin, J. and MacLeod, W. B. (1993). Continuous time repeated games. *International Economic Review*, pages 21–37.

Bigoni, M., Casari, M., Skrzypacz, A., and Spagnolo, G. (2015). Time horizon and cooperation in continuous time. *Econometrica*, 83(2):587–616.

Bochet, O., Page, T., and Putterman, L. (2006). Communication and punishment in voluntary contribution experiments. *Journal of Economic Behavior & Organization*, 60(1):11–26.

Calford, E. and Oprea, R. (2017). Continuity, inertia, and strategic uncertainty: A test of the theory of continuous time games. *Econometrica*, 85(3):915–935.

Chaudhuri, A. (2011). Sustaining cooperation in laboratory public goods experiments: a selective survey of the literature. *Experimental economics*, 14(1):47–83.

Choi, S., Gale, D., and Kariv, S. (2008). Sequential equilibrium in monotone games: Theory-based analysis of experimental data. *Journal of Economic Theory*, 143(1):302–330.

Deck, C. and Nikiforakis, N. (2012). Perfect and imperfect real-time monitoring in a minimum-effort game. *Experimental Economics*, 15(1):71–88.

Denant-Boemont, L., Masclet, D., and Noussair, C. (2011). Announcement, observation and honesty in the voluntary contributions game. *Pacific Economic Review*, 16(2):207–228.

Dorsey, R. E. (1992). The voluntary contributions mechanism with real time revisions. *Public choice*, 73(3):261–282.

Duffy, J., Ochs, J., and Vesterlund, L. (2007). Giving little by little: Dynamic voluntary contribution games. *Journal of Public Economics*, 91(9):1708–1730.

Fehr, E. and Gächter, S. (2000). Cooperation and punishment in public goods experiments. *American Economic Review*, 90(4):980–994.

Fehr, E. and Schmidt, K. M. (1999). A theory of fairness, competition, and cooperation. *The Quarterly Journal of Economics*, 114(3):817–868.

Fischbacher, U. and Gächter, S. (2010). Social preferences, beliefs, and the dynamics of free riding in public goods experiments. *American economic review*, 100(1):541–56.

Fischbacher, U., Gächter, S., and Fehr, E. (2001). Are people conditionally cooperative? evidence from a public goods experiment. *Economics letters*, 71(3):397–404.

Friedman, D. and Oprea, R. (2012). A continuous dilemma. *American Economic Review*, 102(1):337–63.

Gächter, S. and Thöni, C. (2005). Social learning and voluntary cooperation among like-minded people. *Journal of the European Economic Association*, 3(2-3):303–314.

Gunnthorsdottir, A., Houser, D., and McCabe, K. (2007). Disposition, history and contributions in public goods experiments. *Journal of Economic Behavior & Organization*, 62(2):304–315.

Haruvy, E., Li, S. X., McCabe, K., and Twieg, P. (2017). Communication and visibility in public goods provision. *Games and Economic Behavior*, 105:276–296.

Isaac, R. M. and Walker, J. M. (1988a). Communication and free-riding behavior: The voluntary contribution mechanism. *Economic inquiry*, 26(4):585–608.

Isaac, R. M. and Walker, J. M. (1988b). Group size effects in public goods provision: The voluntary contributions mechanism. *Quarterly Journal of Economics*.

Kurzban, R., McCabe, K., Smith, V. L., and Wilson, B. J. (2001). Incremental commitment and reciprocity in a real-time public goods game. *Personality and Social Psychology Bulletin*, 27(12):1662–1673.

Ledyard, O. (1995). Public goods: some experimental results. *Handbook of experimental economics*, 1.

Leng, A., Friesen, L., Kalayci, K., and Man, P. (2018). A minimum effort coordination game experiment in continuous time. *Experimental Economics*, 21(3):549–572.

Marx, L. M. and Matthews, S. A. (2000). Dynamic voluntary contribution to a public project. *The Review of Economic Studies*, 67(2):327–358.

Masclet, D., Noussair, C., Tucker, S., and Villeval, M.-C. (2003). Monetary and nonmonetary punishment in the voluntary contributions mechanism. *American Economic Review*, 93(1):366–380.

Nikiforakis, N. (2008). Punishment and counter-punishment in public good games: Can we really govern ourselves? *Journal of Public Economics*, 92(1-2):91–112.

Oprea, R., Charness, G., and Friedman, D. (2014). Continuous time and communication in a public-goods experiment. *Journal of Economic Behavior & Organization*, 108:212–223.

Radner, R. (1986). Can bounded rationality resolve the prisoner's dilemma. *Essays in honor of Gerard Debreu*, pages 387–399.

Simon, L. K. and Stinchcombe, M. B. (1989). Extensive form games in continuous time: Pure strategies. *Econometrica*, 57(5):1171–1214.

Tan, J. H., Breitmoser, Y., and Bolle, F. (2015). Voluntary contributions by consent or dissent. *Games and Economic Behavior*, 92:106–121.

Walker, J. M. and Halloran, M. A. (2004). Rewards and sanctions and the provision of public goods in one-shot settings. *Experimental Economics*, 7(3):235–247.

Wilson, R. K. and Sell, J. (1997). "liar, liar..." cheap talk and reputation in repeated public goods settings. *Journal of Conflict Resolution*, 41(5):695–717.

Appendices

Appendix A: Proofs

Proof of Proposition 4. Without loss of generality, we rank the players as 1, 2, 3 and 4 by their opting out strategies ($s_1 \leq s_2 \leq s_3 \leq s_4$), e.g., player 1 is the first player who opts out.

First, consider that only player 4 has not opted out, her optimal strategy in this situation is to opt out immediately. This is because further increasing her contribution hurts her payoffs (contributing to public goods yields a return rate of 0.4, and keeping to one's private account yields a return rate of 1, and $0.4 < 1$). Therefore, the last player who stays in should stop contributing as soon as possible.

Similarly, when both players 3 and 4 have not opted out yet, each player's optimal strategy is also to opt out immediately. This is because, even if the remaining two players will both keep contributing, the total return rate 0.8 is lower than the private account return rate 1.

What if only player 1 has opted out? Now the situation is more complicated. Suppose player 2, 3 and 4 stay in and keep contributing, then the total return rate of the public goods is 1.2, which is greater than the private account rate 1. One might think that for player 2, opting out immediately is still a good idea, as for himself, the return rate at his private account is always higher. However, player 2 should be aware that if he opts out, the other two players will opt out immediately! Therefore, given that the other two players' strategies depend on player 2's strategy, player 2 should not opt out too early, as this will lead to the other two players to opt out; player 2 should also not opt out too late, as otherwise the other two players may opt out before him. Since the other two players strategies are s_3 and s_4, with $s_3 \leq s_4$, the best response strategy is $s_2 = s_3 - \tau$. That is, player 2 should opt out just a little before player 3, such that his opting out will not move ahead the opting out time of the second last player. However, by the same argument, player 3 and player 4's best response, given s_2, is to opt out at $s_2 - \tau$. This suggests that when 3 players are remained in the contributing phase, each player's optimal strategy is to be the first to opt out (but just a little bit before the next player), the only equilibrium is that they all opt out at $t = 0$.

Finally, for player 1, his optimal strategy given the remaining three players strategies, is to also opt out at $t = 0$.

Proof of Proposition 5. First, we prove that 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 $\epsilon \geq 24\tau$, then 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 $o \leq \tilde{s} < 1$is an ϵ-equilibrium if $\epsilon \geq 12\tau$.

Proof of Proposition 6. First, we prove that 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 $0 \leq \tilde{s} < 1$. 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 5, 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 $0 \leq \tilde{s} < 1$ 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 CFC)

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 (two decimals 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 this one minute ends, your actual allocation to the public account will be determined by your last intended allocation; meanwhile, your remaining points (20 - the points allocated to the public account) will be automatically allocated to your private account. If you do not send any intended allocation during this minute, the computer will allocate all your 20 points into the private account. At the end of the game, you can see the total points in the public account and your earnings in the game.

Part I (Treatment IC)

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.

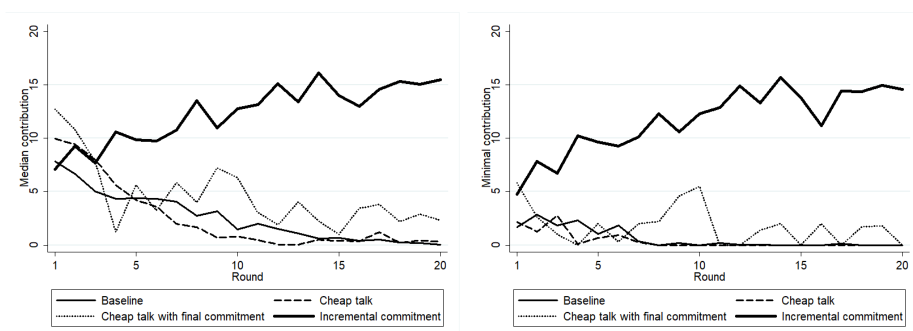

Figure 5: Median (left) and minimum (right) contribution over rounds.

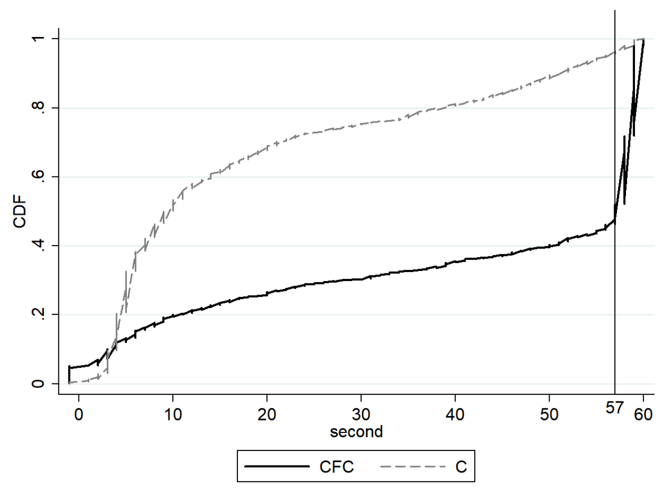

Figure 6: Time distribution of each player's last announcement in C and CFC.