CONDITIONAL COMMITMENTS AND THE VOLUNTARY CONTRIBUTIONS MECHANISM: AN EXPERIMENTAL STUDY

EDİP KART

BOĞAZİÇİ UNIVERSITY

2020

CONDITIONAL COMMITMENTS AND THE VOLUNTARY CONTRIBUTIONS MECHANISM: AN EXPERIMENTAL STUDY

Thesis submitted to the

Institute for Graduate Studies in Social Sciences

in partial fulfillment of the requirements for the degree of

Master of Arts

in

Economics

by

Edip Kart

Boğaziçi University

2020

DECLARATION OF ORIGINALITY

I, Edip Kart, certify that

- I am the sole author of this thesis and that I have fully acknowledged and documented in my thesis all sources of ideas and words, including digital resources, which have been produced or published by another person or institution;
- this thesis contains no material that has been submitted or accepted for a degree or diploma in any other educational institution;
- this is a true copy of the thesis approved by my advisor and thesis committee at Boğaziçi University, including final revisions required by them.

Signature ....

Date ....11.10.2020..

ABSTRACT

Conditional Commitments and the Voluntary Contributions Mechanism:

An Experimental Study

In this paper, we present an agreement mechanism that uses the notion of conditional commitment to reach stable and efficient outcomes in the voluntary contributions mechanism. Theoretically, we show that the use of our conditional commitment mechanism can yield a strong equilibrium at efficient levels so that no agent or a coalition of agents may want to deviate from the corresponding strategy profile. Using data from a public good game experiment, we show that agents can reach the pareto efficient strong equilibrium using conditional commitments. Most agents in the experiment choose to use conditional commitments and in some periods more than 80% of the groups reach agreements that lead them to the efficient outcome although no agent has the opportunity to communicate. We also notice that different commitment levels specified in the mechanism can change the agents' decisions and the usage frequency of the mechanism.

ÖZET

Koşullu Taahhüt ve Gönüllü Katkı Mekanizması Üzerine Deneysel Bir Çalışma

Bu tezde koşullu taahhüt kavramına dayanan ve gönüllü katkı mekanizmasında kararlı ve verimli sonuçlara ulaşabilen bir anlaşma mekanizmasını takdim ettik. Teorik olarak, koşullu taahhüt mekanizmamızın verimli sonuçlar veren güçlü dengeler oluşturabildiğini gösterdik. Bu güçlü dengeler herhangi bir kişinin veya kişilerin oluşturduğu bir koalisyonun bu dengede belirledikleri strateji profillerinden ayrılmamalarını garanti ediyor. Kamu malları üzerine gerçekleştirilen bir deneyden elde ettiğimiz sonuçlar insanların bizim koşullu taahhüt mekanizmasını kullanarak verimli olan güçlü mekanizmalara ulaşabildiğini gösterdi. Deneydeki birçok kişi koşullu taahhütleri kullanmayı tercih etti ve bunun sonucunda bazı periyotlarda grupların %80'inden fazlası katılımcıların iletişim imkanı olmamasına rağmen verimli sonuçlara götüren anlaşmalar yapmayı başardılar. Ayrıca, mekanizmada belirlenen farklı taahhüt miktarlarının kişilerin kararlarını ve mekanizmanın kullanım sıklığını değiştirebileceğini fark ettik.

ACKNOWLEDGEMENTS

I would like to thank my thesis advisor Yeliz Kaçamak for all her help and support. She has ensured that this thesis became better and better. I would also like to thank Mehmet Yiğit Gürdal for his dignified guidance and understanding. His contribution to this paper has been immense. I should also thank Özgür Gürerk and Mehmet Yiğit Gürdal for their contributions to the experimental data. I also appreciate the participation of my committee members Murat Yılmaz and Sinan Ertemel.

I would like to thank the Scientific and Technological Research Council of Turkey (TÜBİTAK) BİDEB for the financial support through the 2210-A Master's Scholarship Program.

Finally, I must mark down that it would not be possible to overcome this period without the support of my friends and family. I should thank them all.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF APPENDIX TABLES

LIST OF FIGURES

LIST OF APPENDIX FIGURES

CHAPTER 1

INTRODUCTION

Public good provision at efficient levels is not an easy target to reach. This difficulty mainly comes from two aspects: the characteristics of public goods and the cooperation failure. No one can be excluded from the use of public good and there is no chance that an agent's consumption can reduce any other's. These properties lead to a common problem of free-riding. As each person is willing to maximize his utility, consuming a public good while not contributing to it can be very beneficial. This free-riding incentive prevents a voluntary contribution mechanism to reach the efficient level of public goods. Furthermore, cooperation of agents in real life is also very difficult to achieve. If agents can cooperate even in a simple Prisoners' Dilemma game, it can easily create better outcomes for both of them. This paper is mainly focused on dealing with these issues and propose a conditional commitment mechanism that can achieve efficient levels of public good provision. Moreover, we will show that our mechanism satisfies an equilibrium concept that is immune to multi-agent deviations. By providing that, we will show that our mechanism can be very useful in real life.

In our mechanism, we simply give agents an option to contribute on a conditional manner with respect to the other agents' choices. Using this option, an agent agrees to contribute a predetermined amount to the public good if others also contribute that amount. On the other hand, he also has the chance not to use it and can decide how much to contribute on his own. If an agent can guarantee that others will participate to the public good provision for sure while he does so, then, assuming public good is beneficial enough for everyone, he will have no incentive to free-ride, but to contribute as others. This conditional agreement removes the coordination failure even if agents have no opportunity to communicate. Also the risk of any loss due to other agents' free-riding is removed. If anyone attempts to free-ride, then by this agreement others will react by not investing the specified amount in the public good. Because this outcome reduces the level of public good, it decreases the agent's payoff and takes any incentive of breaking the deal away.

Alternative mechanisms to these problems mainly provide solutions that can only deal with some of the issues. Most of them only provide an equilibrium for a one-shot game or an equilibrium that is only stable against unilateral deviations. Considering public good provision, it is obvious that we must provide a stronger mechanism that can guarantee more powerful outcomes beyond these. Our mechanism is both useful for repeated games and immune to any deviation in the form of a coalition.

An important feature of this mechanism is that this conditional agreement option is totally voluntary. Anyone can choose not to use this option and play the original game. Thus, we do not need to establish any other game and set any rules or restrictions to achieve desired outcomes. As opposed to that, it must be ensured that this conditional agreement will take place and the terms will be applied.

In our theoretical analysis, we show that using our mechanism we can form a strong equilibrium, which is stable against any deviations of a coalition of players, at efficient levels of public good. In order to have such equilibria we need to set some restrictions on some variables such as the valuation of public good. Also, prescribed commitment levels can change the possibility of reaching an equilibrium. As commitment levels, prescribed contribution amount in the mechanism, decrease, it requires more restriction on variables. Hence, it becomes more difficult to reach the equilibrium.

Our theoretical findings are also supported with data coming from a laboratory experiment on public good games. The game simply asks the participants to decide how much to invest in a group project. The design is similar to a general public good game, yet there is an extra question for the players to answer: whether to use the conditional commitment mechanism. Using this mechanism, the agent agrees to make the predetermined contribution if all other agents also agree to use the mechanism. Every agent has the same endowment level and they all value the public good the same. Players move simultaneously and the communication is forbidden. All this information is common knowledge to everyone. Subjects, at the same time, decide whether to use the mechanism (without any cost) and how much to invest if an agreement does not occur. Keeping the members of each group the same, they all asked to play this game repeatedly for 10 periods.

In the experiment, we observe that most participants use the conditional commitment agreement and this leads them to have an agreement at efficient level. There are two different commitment levels in the experiment. This commitment levels specify the contribution amount that agents make if they use the mechanism. For higher commitment levels, we find out that both the usage of conditional commitments and the amount of agreements reached is higher. Lower commitment levels lead some agents not to use the mechanism and contribute more than the predetermined amount so that they can make a Pareto improvement.

In section 2, a brief summary of the related literature is presented. Then, in addition to our mechanism an alternative one is also analyzed theoretically in section 3. Section four reveals the experimental design and procedures. Following that, section five gives the experimental results while conclusion remarks are presented in the last section.

CHAPTER 2

LITERATURE REVIEW

Theoretically our concept will mainly be supported by the notion of strong mediated equilibrium in Monderer and Tennenholtz (2009). It discusses that by the use of mediators we can reach outcomes that are strong equilibria. And by strong equilibria it refers to the equilibria where a deviation by any coalition of the agents is not profitable. So, these equilibria are more powerful than the Nash equilibria. Considering Nash equilibria only assure for unilateral deviations, this strong equilibria concept can be considered more useful for public good provision issue. A mediator is defined as a credible person or a program that can act on the behalf of an agent. Mediators receive some messages from the agents and decide which action to choose on a prescribed rule. Since these mediators are credible it is sure that they perform according to the rules defined earlier.

The use of mediators is totally voluntary so that players can choose not to use them and decide on their own. This feature perfectly fits into our mechanism. Monderer and Tennenholtz (2009) explains that this setting gives simpler solutions than a mechanism design setting. In the theory of mechanism design, a new set of game must be constructed right from the beginning, but in this context agents are just given an option to use mediators. So, outcome is simply an expansion of the original game with a new set of choices.

A strong equilibrium achieved through the use of mediators is defined as strong mediated equilibrium. Furthermore, with the concept of mediators defined, they prove that efficient outcomes can be attained and will be immune to any deviations by coalitions thanks to the use of mediators. In the next section, we will try to show that our mechanism can create a strong mediated equilibrium.

Tennenholtz (2004) presents program equilibrium notion which can be viewed as a special type of strong mediated equilibrium. In this context computer programs serve as a mediator to the agents. Tennenholtz (2004) argues that computer programs can both operate as a number of commands and as a file to be read. So, these programs can compare themselves with others. Using this logic, agents with the help of computer programs can take actions considering other agents' choices. A program as a mediator takes the messages (instructions) from the agent and compare itself with the opposing program. Consider the simple prisoners' dilemma game in this context. Now, agents can run a computer program that can choose actions, cooperate and defect, with respect to the other agent's program choice. If the syntaxes are matched, then the program produces the action to cooperate, otherwise chooses to defect. Tennenholtz (2004) shows that by using computer programs, a program equilibrium can be achieved and this equilibrium is stable against any deviation of the players. Thus, desirable outcomes are attainable.

Another related equilibrium concept is defined in Kalai et al. (2010). For any two person strategic game, it explains the commitment folk theorem as follows: using commitment devices which are voluntary, the Nash equilibria outcomes of the game with commitments can span all the feasible and individually rational payoffs that can be gained in the original game. Kalai et al. (2010) again gives an option to the players to choose their actions conditioning on the other's. Agents give the commitment device the right to choose their actions, but the action the device would undertake is not unconstrained. There is a device response function that decides the strategy according to a set of predetermined rules. A commitment device can be an announcement or an agreement or a money-back guarantee. The important point is that when a device is used, agents guarantee that they will follow the outcome of the commitment device game.

Kalai et al. (2010) also argues that conditional commitments to an action can yield a circularity. To prevent this, commitment devices should condition its chosen action on the other agent's device choice not on the action opponent's device would choose. Moreover, it shows that for any two-person game a voluntary space of commitment devices exists.

In the literature there are some mechanisms that can be considered an alternative to our mechanism for public goods. Reischmann and Oechssler (2018) designs a binary conditional contribution mechanism where an agent conditions his contribution on the participation number of the other agents. Namely, an agent can restrict his participation to the public good provision on a specific number of attendance in total. Players reveal their choice of restriction by messages. Consider a five-agent game. In this game one can send a message that contains the following meaning: if at least $k \leq 5$ agents accept to participate, then he also chooses to participate. Reischmann and Oechssler (2018) argues that unlike other mechanisms their construction (with some restrictions over chosen messages) allows stable solutions for dynamic settings. Also, it shows that once an efficient outcome is reached in this mechanism, this outcome will be stable over time. Another important aspect is that inefficient outcomes are likely to be left over time in this mechanism. So, even if we start at an undesirable point, the mechanism allows us to move forward to more efficient points.

Although binary conditional contribution mechanism has some important features, our mechanism yields an expanded framework for the issue. First, unlike that mechanism we also offer agents to decide their own contribution level as an alternative outcome. Binary contributions only have the contribution option of 0 and 1. Nevertheless, in our setting conditional contribution is totally voluntary whereas Reischmann and Oechssler (2018) only looks for the equilibrium of its mechanism. We will also try to find if their mechanism can construct a strong mediated equilibrium.

Admati and Perry (1991) is one of those who uses conditional commitments notion in public good games. It mainly discusses a contribution game where the completion of a joint project depends on a total contribution threshold and no enforceable contracts or commitments is possible. In a complete and perfect information environment, two agents are expected to take turns and make their contributions when their period is arrived. The cost of the project, namely the agents' contributions, is sunk when contributions are made and agents could only get benefits if the project is completed. It shows that when no commitments are made, some socially beneficial projects are not completed in equilibrium and thus, the outcomes are not inefficient. Then, it presents the subscription game where each agent can commit their contributions upon the other agent's. So, the cost of the contributions occurs only when the project is completed. The subscription game yields a unique equilibrium in which the project is completed if the cost is low enough that the project is desirable.

Compte and Jehiel (2003) redesigns Admati and Perry (1991)'s model and uses asymmetric agents. It points out that the equilibrium characteristics of the joint projects is to make small contributions at every period. In equilibrium, it requires many periods to complete a project. It argues that as opposed to Admati and Perry (1991)'s results, it cannot be concluded that this equilibrium path emerges due to sunk cost of the contributions. It shows that when the agents' valuations of the public good are asymmetric, it is possible to reach an equilibrium where contributions are large and made at the first turn of the agents.

Varian (1994) proves that in a voluntary contribution public good game, the level of the public good provided decreases or stays the same when agents move sequentially compared to when they move simultaneously. It uses quasilinear utilities and shows that the agent who values less the public good prefers to contribute first.

Based on the public goods which it requires many periods to raise enough fund and where agents make contributions considering the total contributions made, Marx and Matthews (2000) constructs a dynamic voluntary contribution model. Agents can make their contributions in every period, yet cannot know how much contribution others make. They can only observe the total investment made. It shows that under certain circumstances, a perfect Bayesian equilibrium can arise where the completion of the project is possible.

CHAPTER 3

THEORETICAL ANALYSIS

First, we define a voluntary contribution mechanism (VCM) setting for a general public good game. A game in strategic form is defined by a tuple $\Gamma = (N, \{X_i\}_{i\in N}, \{u_i\}_{i\in N})$, where $N = \{1, \ldots, n\}$ is the set of agents, X_i is a finite, nonempty strategy set of the player i , and $u_i : X \to \mathbb{R}$ is the utility function for player i. Also define the strategy set of players as X = $X_1 \times X_2 \times \ldots X_n$.

There is only one public good and each player chooses how much to contribute. Players have an endowment of ω which they can either choose to keep to themselves for the private good or give a portion to the public good. Let $x_i \in \{0, 1, \ldots, \omega\}$ define the amount of investment in the public good for player i. Also assume that there cannot be any transfer to the players or within the players.

We assume a linear utility function that represents preferences of the agents. Each unit of the endowment gives a utility of 1 to a player if he chooses not to contribute. Public good valuations differ for everyone and are denoted by γ_i for each player i. Then, utility of an agent can be written as:

$$u_i = \omega - x_i + \gamma_i \sum_{j=1}^{n} x_j \tag{3.1}$$

Assume $\gamma_i \in [0, 1)$ so that if an agent invests in the public good on his own, it worsens the agent. This assumption is necessary for our mechanism's argument since for any player with $\gamma_i \geqslant 1$ investing in the public good is a dominant strategy. Because in that case every contribution an agent makes to the public good returns a higher payoff than the any amount the agent keeps for himself. Nevertheless, for any $\gamma_i < 0$ the agent gets negative utility from the public good so that investing in the public good is never a profitable strategy for that agent. Also, as the utility function suggests, a player chooses not to participate if $\gamma_i = 0$.

As in Reischmann and Oechssler (2018), we also assume that there are some players that can improve their utility by investing in the public good. To ensure that some of the players' valuations, γ_i, must be bigger than some critical level as stated below. In formal:

$$\exists\, k \in \{2, \ldots, n\} \quad and \quad i_1, \ldots, i_k \in N: \quad \gamma_i > \frac{1}{k}, \quad \forall i \in \{i_1, \ldots, i_k\} \tag{3.2}$$

In words, there exist at least two agents whose valuations are high enough to make more payoff by investing in the public good. Assuming there are only two agents that fulfill this requirement, their valuations must be bigger than 1/2. If all the agent's valuations meet this condition, then it should be satisfied that $\gamma_i > \frac{1}{n}, \quad \forall i$.

Proposition 1: In a VCM setting, given $\gamma_i \in [0, 1)$, Nash equilibrium strategy of any player i is not to contribute.

Proof: A strategy profile is a Nash equilibrium if no agent can improve his payoff by deviating unilaterally. Considering the utility function in equation 3.1, marginal utility of an agent i, given other players' strategies, from contributing to the public good is $-1 + \gamma_i$. Since we assume that $\gamma_i \in [0, 1)$, marginal utility of a player i is negative, $-1 + \gamma_i < 0$. Hence, best response of a player is always contributing zero to the public good. Then, Nash equilibrium of a public good game in a VCM setting is {0,0, . . . , 0} where strategies are contribution levels.

Since the valuation of the players for the public good, γ_i, is less than 1, any unilateral deviation from this profile worsens the player by reducing his payoff. So, without any coordination no public good will be provided.

Proposition 2: In a VCM setting, given $\gamma_i \in [0, 1)$ and $\gamma_i > \frac{1}{n}\, \forall i \in$ N, full contribution to the public good by all agents is a Pareto optimal outcome.

Proof: Pareto efficiency is achieved when there cannot be a strategy profile that can give more payoff to an agent without making any other players worse off. Assuming full contribution is a Pareto optimal outcome, any deviation by a player or a coalition of players should worsen at least one of the agents. In full contribution case, every agent gets a payoff of $\gamma_i n\omega$. Consider a coalition of agents, $S \subseteq N$, deviates from this strategy profile. Let |S| = s. Also, let S^c be the complements of the set S. Members of this coalition can make contributions $x_i^S \in \{0, 1, \ldots, \omega\}$ and every agents' contributions may differ. Assume that total contribution this coalition makes is x_S. Agents in S^c still contributes ω units to the public good. Then, the utility of an agent in S can be written as: $u_i^S = \omega - x_i^S + \gamma_i[(n-s)\omega + x_S]$. Also, utility of an agent in S^c is $u_i^{S^c} = \gamma_i[(n-s)\omega + x_S]$. Since $x_i^S \leq \omega$, $x_S \leq s\omega$. Then, $u_i^S \leq \omega - x_i^S + \gamma_i n\omega$ and $u_i^{S^c} \leq \gamma_i n\omega$. For a Pareto improvement there cannot be a player that worsens. Hence, utility of agents in S^c should not be less than their initial levels. So, $u_i^{S^c} < \gamma_i n\omega$ cannot be the case. Knowing that $u_i^{S^c} = \gamma_i n\omega$, $x_S = s\omega$ should hold. But, then $u_i^S = \gamma_i n\omega$ should also hold. Thus, no Pareto improvement is possible for a full contribution strategy profile. Full contribution in a VCM setting is a Pareto efficient outcome.

3.1 The conditional commitment mechanism

We now introduce our mechanism for the public good provision, which gives players an option of conditional contribution. The mechanism is a tuple $T = (\{m_i\}_{i \in N}, r)$ where m_i is the message player i can choose for the participation to the conditional commitment mechanism and $r : M \to x_i$ is defined for the response function of the mechanism where $M = m_1 \times m_2 \times \ldots \times m_n$. So, our mechanism creates an expanded model of the original game where a strategy set of player i is now $Z_i = m_i \times S_i$.

The message space for our mechanism can be a singleton or consist of multiple elements. Although we provide further analysis for larger message spaces in the next sections, here for simplicity we assume that the message space is singleton and for player i it is: $m_i = c$ or $m_i = \emptyset$. If a player decides to use the conditional commitment mechanism, then he sends a message c to the mechanism. Here, c stands for the predetermined commitment level in the mechanism and it should be less than or equal to the endowment level of the players, $c \in [0, w]$. By sending a message c, an agent agrees to invest c in the public good if every agent chooses to use the mechanism. In case an agent does not send a message through the mechanism, all agents who send message c contribute zero. Agents can also choose not to send a message and decide their own contribution levels.

The response function of the mechanism is predetermined and works as follows: "If all other players choose the message c, that they would like to participate in the conditional commitment mechanism, then all players invest c in the public good. Otherwise, those who choose message c contribute zero, and those who do not send a message choose their own contribution."

Using our mechanism, we can construct a Nash equilibrium outcome at Pareto efficient levels where every agents fully contribute. Suppose every player agrees to run the mechanism and $c = w$, then all of the endowments of the players will be invested in the public good. Thus, total contribution level will be $n\omega$ and player i gets a payoff of $\gamma_i n\omega$. Using the assumption in equation (2), when $k = n$, $\gamma_i > 1/n \ \forall i$, we ensure that $\gamma_i n\omega > \omega$. So every player is better off. Even a player denies to participate in the mechanism, then conditional commitment mechanism yields zero contribution of the agents and Pareto efficiency is not achieved.

3.2 Strong mediated equilibrium (SME)

Define a finite strategic game $\Gamma = (N, \{X_i\}_{i \in N}, \{u_i\}_{i \in N})$, where $N = \{1, \ldots, n\}$. X_i and u_i denotes the strategy set and payoff of player i, respectively. Let $S \subseteq N$ be a coalition and denote $X_S = \prod_{i \in S} X_i$, where X_S is the strategy profile of the players in coalition S. Also let S^c be the set which contains the members outside the coalition.

A mixed strategy of a player i is a probability distribution over X_i, which we denote by $\theta_i = \Delta(X_i)$. Then, for any coalition S, we can define a mixed strategy profile as $\theta_S = \prod_{i \in S} \Delta(X_i)$.

A correlated strategy for S can be denoted by $c_S \; \in \; \Delta(X_S)$.

A strategy profile is a strong equilibrium if no member of any coalition S can improve his utility by deviating from the selected strategy profile. Monderer and Tennenholtz (2009) defines three types of strong equilibrium, but here, we only focus on one type of these equilibria which is sufficient for our analysis.

Definition 1: Let q ∈ θ be a mixed strategy profile where $q = (\theta_1, \ldots, \theta_n)$. Then, q is a strong equilibrium of type III , if for every coalition S, and for every correlated strategy for S, $c_s \; \in \; \Delta(X_S)$, there exists a j ∈ S such that

$$u_j(c_s \times \prod_{i \in S^c} \theta_i) \; \leq \; u_j(\theta_1 \times \theta_2 \times \ldots \times \theta_n). \tag{3.3}$$

As it can be interpreted from the above definition, a strong equilibrium of type III ensures that there exists at least one agent that cannot make higher profits by deviating any other strategy profile. Hence, a deviation by a coalition S can occur only if all members of the coalition are strictly better off.

A mediator is an entity that can react on behalf of a player. Players send a message to the mediator and according to a prescribed action function, the mediator decides which strategy to choose. The use of the mediator is totally voluntary.

Definition 2: For a finite game Γ, a mediator is a tuple $\mathcal{M} = (\{M_i\}_{i \in N}, \alpha = (\alpha_s)_{\emptyset \neq S \subseteq N})$, where each M_i is a finite set, $M_i \cap X_i = \emptyset$ for every player i, and for every coalition S, $\alpha_S : M_S \rightarrow \Delta(X_S)$.

$\alpha = (\alpha_s)_{\emptyset \neq S \subseteq N}$ stands for the action function of the mediator. If a set of players, S, chooses to use the mediator, then message profile is $m_S = \{m_i\}_{i \in S}$ and the action function is $\alpha_S(m_S)$. The mediator then determines the strategy profile x_S for the players.

Any mediator $\mathcal{M}$ for Γ constructs a new game which is called the mediated game and denoted by $\Gamma(\mathcal{M})$.

Definition 3: Let Γ be a game in strategic form. A correlated strategy $c \in \Delta(X)$ is a strong mediated equilibrium if there exists a mediator for Γ, $\mathcal{M}$, and a vector of messages $m \in M = \prod_{i \in N} M_i$, with $\alpha_N(m) = c$ such that m is a strong equilibrium of type III in $\Gamma(\mathcal{M})$. Such a mediator is said to strongly implement c.

Also, a minimal mediator is defined where each message space is a singleton. Monderer and Tennenholtz (2009) proves that a minimal mediator can implement any strong mediated equilibrium in Γ.

3.3 The conditional commitment mechanism and SME

In our set-up, the mechanism acts as a mediator. It receives messages from the players and chooses an action on behalf of them. As defined above, our mechanism is a tuple $T = (\{m_i\}_{i \in N}, r)$ which completely fits the definition of a mediator. Our setting enables the players a message space of $m_i = \{\mathrm{c}\}$. By definition, it can be concluded that this mechanism is a minimal mediator. As mentioned above, using a minimal mediator does not distort any analysis made in the concept of strong mediated equilibrium.

Theorem 1: Given $\gamma_i > 1/n$ for all i, all players using the mechanism and investing all of their endowments in the public good, when $c = w$, is a strong mediated equilibrium.

Proof: We need to show that the use of mechanism, that is sending message $c = w$ to the mediator is a strong equilibrium in the mediated game. A message profile $m_i = w$ for all $i \in N$ is a strong equilibrium of the mediated game if there is no coalition that can improve any of its members' payoff.

If all players send the message $c = w$ to the mediator, the outcome will be investing the whole endowment, ω, for all player i. Thus, every player i gets a payoff of $\gamma_i n \omega$.

Let $S \subseteq N$ be the coalition of the players who decide to deviate. Also let |S| = s. Assume that every member of this coalition, while not sending message, now decides to contribute an amount of τ_i to the public good, where $0 \leq \tau_i \leq \omega$. Also let τ denote the total contribution level this coalition now makes, namely $\tau = \Sigma_{i \in S} \tau_i$.

Since a number of players now decide not to participate in the mechanism, the response function requires that other players will contribute zero. Denote the set of these other players by S^c, the complement of S. Thus, no player in S^c invests in the public good. Then, we can define the payoff of the players that participate in coalition S as follows: $u_i^s = \omega - \tau_i + \gamma_i \tau$. If this utility is less than or equal to the utility players get by using the above message profile, then, we can conclude that playing that message profile is a strong mediated equilibrium for the mediated game. Thus, the following inequality must hold.

$$\begin{aligned} \omega - \tau_i + \gamma_i \tau &\leq \gamma_i n \omega \\ \omega - \tau_i &\leq \gamma_i (n\omega - \tau) \\ \frac{\omega - \tau_i}{n\omega - \tau} &\leq \gamma_i \end{aligned} \tag{3.4}$$

Since |S| = s $\leq n$, τ_i/τ is greater than or equal to $1/n$ for at least one $i \in S$. Thus, the left side is smaller than or equal to $1/n$ for at least one $i \in S$. Since $\gamma_i > 1/n$ for all $i \in N$ by assumption, the inequality holds for at least one $i \in S$ and he doesn't benefit from deviating. We conclude that $m_i = \omega$ for all $i \in N$ is a strong equilibrium of the mediated game.

Hence, it can be interpreted that for any γ_i big enough so that every agent makes profit if all agents invest in the public good, our mechanism provides a strong mediated equilibrium. That is, no single player or a group of players would like to deviate from the strategy profile they choose in equilibrium. The intuition for this result is as follows: If there are players that care about the public good, then any change reducing the provision of the public good, breaking the conditional commitment agreement, will harm these agents and in advance force them to stick with their strategy. So, no coalition can give any incentive to those players to break the conditional commitment agreement.

This conclusion also shows that by this mechanism we can reach the efficient level for the public good, which is the full contribution of the all players.

Suppose that the members of the coalition S decide to not contribute. Then, (3.4) becomes:

$$\frac{1}{n} \leq \gamma_i$$

Thus, if γ_i is bigger than $1/n$ for any player i, then nobody can profitably deviate to a non-contribution case by a coalition. So, the mechanism overcomes the free-riding problem for the full commitment case.

3.4 Equilibrium examples

Studying some examples could give more insights for the above inequality (3.4).

Example 1: Consider a five-agent public good game where each player has an endowment of ω. Let $\gamma_i = 0.1$ for all i. If all agents choose to use the mechanism by sending a message $c = w$, then, all of them end up with investing an equal ω units in the public good. In that case, total public good provided will be 5ω and everybody will get a payoff of 0.5ω. Obviously, this strategy profile is not individually rational and thus not a strong mediated equilibrium, because anybody could get a higher payoff by not using the mechanism and not contributing.

Example 2: Again consider five agents with ω endowments. But now, let $\gamma_i = 0.4$ for all agents. By using the mechanism with above message profile, 5ω units of public good will be provided. Then, each agent gains a utility of 2ω, which is higher than what they would get without investing. Assume that an agent decides to deviate from this profile. This unilateral deviation will cause the conditional commitment agreement to fail. As other four agents do not contribute, this deviation cannot yield a higher payoff for the agent. If he invests $0 < \tau \leq w$ in the public good, he surely gets a payoff of less than ω since $\gamma_i < 1$. Moreover, if he chooses not to contribute, he gets ω utility, which is less than 2ω. In every case, he is worse off. So, this profile is a Nash equilibrium. Now, assume that a coalition of the players wants to deviate. Let $S \subseteq N$ be that coalition and S^c be the set of players that is not in the coalition. Also let $|S| = s \leq 5$. Then, any player in S^c does not contribute. If the members of this coalition S also decide not to contribute, then they get a payoff of ω each. Since it is less than the utility they can receive with the mechanism and message profile above, it is not profitable. Furthermore, the coalition S can mostly create a public good provision of $s\omega$, which is less than or equal to 5ω and members of this coalition can get a utility less than or equal to 2ω. Again, this deviation is not profitable and we can conclude that our mechanism yields a strong mediated equilibrium.

To find the threshold for γ_i in these examples, consider inequality (3.4) above. Simply let $\tau = s\tau_i$ and $\gamma_i = \gamma$ for all i. Then, $(\omega - \tau_i)/(5\omega - s\tau_i) \leq \gamma$. Considering a coalition of five, this inequality yields that for any $\gamma \geq 0.2$ our mechanism creates a strong mediated equilibrium.

This set-up is also consistent with any example where agents have dissimilar γ_i's. In order to achieve a strong mediated equilibrium, the most restricted inequality need to be implemented for any γ_i. In other words, all γ_i's should be above the highest threshold.

3.5 Lower commitment levels

In this section, we examine if our mechanism also works under other circumstances where players do not fully contribute. In this set up, we still use the same message space and give the response function the right to choose contribution levels for the agents if the mechanism is used by all. Only change here is that, agents by using the mechanism, agree to invest some $k < \omega$ units in the public good, which is predetermined in the response function. Then, our response function can be updated as follows:

”If all other players choose the message k, that they would like to participate in the conditional commitment mechanism, then all players invest k in the public good. Otherwise, those who choose message k contribute zero, and those who do not send a message choose their own contribution.”

As discussed in previous chapters, this mechanism also creates a mediated game where the mechanism is a mediator and the message space is a singleton, $m_i = \emptyset$ or $m_i = k$.

Proposition 3: For any given γ_i, conditional commitment mechanism cannot provide a strong mediated equilibrium for commitment levels lower than the endowment.

Proof: We need to check if there can be any profitable deviation for a coalition. Then, a comparison of the utilities is needed.

Suppose everybody uses the mechanism by sending message k to the mechanism. Using the utility function in (3.1), payoff of the players becomes: $u_i = \omega - k + \gamma_i nk$. Now, suppose that there is a coalition of the players who decides to deviate from this strategy profile. Denote this coalition by S and the complement of it by S^c. Also let τ_i represent the contribution level of the players in S and τ the total contribution of the coalition S. Nobody in S^c invests in the public good since conditional commitment agreement breaks apart. Then the utility level the members of this coalition can get is: $\omega - \tau_i + \gamma_i \tau$. Hence, above message profile using the mechanism could be a strong mediated equilibrium only if this deviation cannot provide more payoff for coalition members. Formally;

$$\begin{aligned}
\omega - \tau_i + \gamma_i \tau &\le \omega - k + \gamma_i n k \\
k - \tau_i &\le \gamma_i (nk - \tau) \\
\frac{k - \tau_i}{nk - \tau} &\le \gamma_i \qquad (3.5) \\
or \quad \frac{\gamma_i \tau - \tau_i}{\gamma_i n - 1} &\le k \qquad (3.6)
\end{aligned}$$

It can be concluded from the equation (3.6) that for any given γ_i, k must be big enough to avoid players deviating from their strategy profile. Thus, we cannot have a strong equilibrium if the commitment level is lower than the endowment.

Suppose that there is an n-person coalition, i.e. everybody cooperates to deviate to a different strategy profile. Also, for simplicity let $\tau = n\tau_i$. Then, from (3.5) and (3.6) it can be inferred that $1/n \le \gamma_i$ and $\tau_i \le k$ should hold. Yet, it is known that $0 \le \tau_i \le \omega$ and $0 \le k < \omega$, which means τ_i could be bigger than k. Furthermore, for an n-person coalition case with $1/n \le \gamma_i$, fully contribution always yields higher payoff. So, there is a profitable deviation for the players. Thus, we can conclude that for any k less than full contribution our mechanism cannot provide a strong mediated equilibrium.

Some comparative statistics may lead to deeper understanding of the stability of our mechanism. Let $|S| = s$ and for simplicity assume that $\tau = s\tau_i$. Rearranging (3.5) and (3.6) yields:

$$\begin{aligned}
\frac{k - \tau_i}{nk - s\tau_i} &\le \gamma_i \qquad (3.7) \\
or \quad \frac{\gamma_i s \tau_i - \tau_i}{\gamma_i n - 1} &\le k \qquad (3.8)
\end{aligned}$$

Then, inequalities (3.7) and (3.8) declares that as s gets higher, the requirement on k and γ_i gets harder. Formally, as $s \to n$, γ_i should become bigger than $1/n$ and k should converge to ω. To conclude, we can say that the possibility that we can have a strong mediated equilibrium decreases as k and γ_i decreases. To have more stable outcomes, we need to implement stricter conditions.

3.6 Larger message space

As an alternative, we can construct a mechanism where the message space is larger and agents can send messages that contain more information. For instance, consider a message space $M_i = \{c_0, c_1, \ldots, c_w\}$ for a player i, where the message c_j has the following meaning: "If all other players choose to send a message, then invest c, the predetermined commitment level, in the public good. Otherwise, contribute j units out of ω, my endowment level".

The message c_0 in this message space corresponds to the singleton message space we defined earlier in section 3.3. The agent confirms the usage of the mechanism and agree to invest c units if all other players also choose to send a message. Otherwise, he will contribute zero to the public good.

As Monderer and Tennenholtz (2009) discussed, a minimal mediator where the message space is singleton can implement any strong mediated equilibrium in a mediated game. Thus, dealing with a single message space does not eliminate any outcomes nor make any analysis inadequate.

3.7 Other related models

The environment we construct for the public good game is different from some of the papers in the literature. In this section, we will try to examine how results could change when we modify our setting and refer to a paper which similarly uses the conditional commitments notion.

Admati and Perry (1991) argues that in a sequential contribution game where contribution costs are sunk once they are made, outcomes are socially inefficient. Then, it presents a subscription game in which agents can make conditional commitments to contribute. In this setting, contribution costs arise only if sufficient amount of contributions are made to complete the project. It shows that in the subscription game when the total cost of the project is small enough there is a unique equilibrium that enables the project to be completed. Considering the usage of conditional commitments, Admati and Perry (1991) examines a similar structure as ours. Yet, apart from their analysis we offer the usage of commitments to be totally voluntary and show that the mechanism is useful for multi-agent environments both in a static and dynamic setting. Moreover, as the main result we prove that using our mechanism we can construct a strong equilibrium.

There are some papers which uses quasilinear utility functions for the public good game as Varian (1994). Consider a quasilinear utility function for our setting: $u_i(x_i, z) = \omega - x_i + v_i(z)$ where $z = \sum_{j=1}^{n} x_j$ is the level of public good. Also, note that v_i is strictly increasing and concave in z. As opposed to a linear utility function, using quasilinear utilities will produce a Pareto optimal outcome lower than full contribution, considering the properties of the function. But, we would still be able to construct a strong mediated equilibrium at Pareto efficient levels because then again any deviation of a coalition hurts the deviating agents. Considering there cannot be a Pareto improvement over a Pareto optimal outcome, the mechanism enables to punish any deviation from the efficient level.

Now, suppose that the endowments of the agents are different so that each agent has ω_i endowment. Then, inequality 3.4 becomes $(\omega_i - \tau_i)/(\sum_i \omega_i - \tau) \leq \gamma_i$. Since |S| = s $\leq n$, τ_i/τ is greater than or equal to $\omega_i/\sum_i \omega_i$ for at least one $i \in S$. Thus, the left side is smaller than or equal to $1/n$ for at least one $i \in S$. Since $\gamma_i > 1/n$ for all $i \in N$ by assumption, the inequality holds for at least one $i \in S$ and the agent doesn't benefit from deviating. We can conclude that considering ω_i, $m_i = \omega$ for all $i \in N$ is still a strong equilibrium of the mediated game.

In public good games, it is common to assume that a public good can be provided only if total amount of investments exceeds a threshold. Compte and Jehiel (2003) is one of those papers which examine a threshold public good game considering asymmetric agents. Marx and Matthews (2000) can also be stated as an example to those. It studies dynamic voluntary contribution to the public good where agents can contribute in every period and choose their strategy upon the total contribution level. In these settings, players are expected to consider not only their utilities from the public good but also the probability whether the public good can be provided with their contribution. In this paper, we rule out this assumption and focus on the level of the public good, that is every investment in the public good increases the level of public good provided. By doing that, we simplify the set-up and focus on the optimal levels so that agents do not hesitate to contribute considering there may occur a sunk cost. Thus, our main question is converted from whether the public good provided to whether the optimal level be reached. Admati and Perry (1991) studies a threshold public good game and suggests using conditional commitments to reach socially desirable levels. Considering this, our mechanism could also be applicable for a threshold game.

For the voluntary contribution mechanism, we enable players a discrete strategy set: $x_i \in \{0, 1, \ldots, \omega\}$. A continuous strategy as $\bar{x}_i \in [0, \omega]$ would provide players infinite number of strategies. Yet, our discussions for strong mediated equilibria would stay the same. A full contribution case is still a Pareto optimal outcome in that set-up and we can still construct a strong mediated equilibrium using the strategy profile in Theorem 1. As long as a linear utility function is used, a strong equilibrium is not possible for lower commitment levels because an n-player coalition can deviate to full contribution and have a strictly higher payoffs.

3.8 Binary conditional contribution mechanism and SME

Reischmann and Oechssler (2018) presents the Binary Conditional Contribution Mechanism (BCCM) for public good provision. This mechanism simply gives agents the right to participate in the system with a conditional participation agreement through messages. In that set up, agents send messages to the mechanism and the mechanism reveals how many agents should contribute to the public good provision.

Reischmann and Oechssler (2018) studies BCCM in a dynamic setting, yet in this paper we will focus on a static environment. There is a set of individuals $I = \{1, 2, \ldots, n\}$, each endowed with one monetary unit. Each agent can decide whether to invest that one unit in the public good or to spend it for the private good. Outcome space is denoted by $z = \{z_1, z_2, \ldots, z_n\}$ with $z_i \in \{0, 1\}$. Here z_i stands for player i's contribution to the public good. If $z_i = 0$, then player i does not contribute, but if $z_i = 1$, then he fully invests in the public good. Each unit of the private good provides one unit of utility to the agents, whereas a unit of public good yields a utility of $\theta_i \ \in \ [0, 1)$ to the player i. Thus, utility function of a player i is:

$$u_i(z) = 1 - z_i + \theta_i \sum_{j=1}^{n} z_j \tag{3.9}$$

They also assume that the property (3.2) holds.

BCCM constructs a game $G^{BCCM} := (M^{BCCM}, g^{BCCM})$ where the message space is M^{BCCM} and outcome function $g^{BCCM} : M^{BCCM} \to Z$ links these messages to the outcome space. Each player i can choose messages from the message space $M_i^{BCCM} = \{1, 2, \ldots, n+1\}$. A message $m_i = k$ has the meaning of agreeing to contribute if at least k agents (including himself) contribute to the public good. The message $m_i = n + 1$ means that the player i never contributes to the public good while a player with a message $m_i = 1$ guarantees that he always invests in the public good. For any message profile of the players, the mechanism chooses the highest possible contribution level which fits with all the messages.

Consider n agents. If everybody sends the message $m_i = 1$, then everybody contributes. If player 1 and 2 choose $m_i = 3$, player 4 and 5 choose $m_i = 4$ while others choose $m_i = n + 1$, then the outcome is: $z = \{1, 1, 0, 1, 1, 0, 0, \ldots, 0\}$. Four agents contribute to the public good while others free-ride.

We slightly modify this original setup in order to have a mediated game defined in section 3.2 so that players can choose their strategies by not sending a message. We assume that agents can choose to send a message $m_i \in M_i = \{2, 3, \ldots, n\}$ or not to send a message and play their own strategy $z_i \in Z_i = \{0, 1\}$. Let S be the set of players who send a message, then $m_S = \{m_i\}_{i \in S}$ is the message profile of the players in set S and $\alpha_S(m_S) \in \Delta(Z_S)$ is the outcome function. Also define S^c to be the set of agents who do not send a message and choose their own strategy. The mechanism selects the outcome with the highest possible contribution level according to chosen message and strategy profiles. In formal, we can define;

$$K(m) := max \left\{ k \in \{0, 1, \dots, n\} \middle| \left[\sum_{j \in S} \mathbb{1}_{m_j \leq k} + \sum_{j \in S^c} \mathbb{1}_{z_j = 1} \right] \geq k \right\} \tag{3.10}$$

For each $i \in S$, $\alpha_S(m_S)$ assigns probability 1 to $z_i = 1$ whenever $m_i \leq K(m)$ and probability 1 to $z_i = 0$ otherwise.

BCCM produces many Nash Equilibria including the zero-contribution case. Although these equilibria is strong for unilateral deviations, Reischmann and Oechssler (2018) argues that within these equilibria only Pareto efficient ones survive after a reasonable dynamic adjustment process. These Pareto efficient Nash equilibria can be reached by unexploitable messages. Reischmann and Oechssler (2018) explains this term as follows: unexploitable messages ensure that an agent cannot get lower payoff in the next period considering any deviation of another player, even though the agent has to contribute then. Using unexploitable messages, agents can discourage others from free-riding. Formally, these messages should satisfy two conditions. Contributing agents should send messages that can cover at least the total present contribution level. Besides, non-contributors should still free-ride unless there occurs a possible improvement on the total level of public good that is more than $1/\theta_i$ (including himself). So, using unexploitable messages we can reveal outcomes that are both Nash equilibria and Pareto efficient.

Using this reasoning, this paper claims that Pareto efficient outcomes reached by unexploitable messages can constitute strong equilibria and these equilibria BCCM yields are strong mediated equilibria.

According to the definition of a mediator, it can easily be said that the redesigned BCCM can act as a mediator. Then, if a message profile can create a strong equilibrium of type III in the mediated BCCM game, it can be concluded that using that message profile constitutes a strong mediated equilibrium.

First, we try to show with a counter example that not all Nash equilibria are strong mediated equilibria or Pareto efficient. Assume that nobody contributes to the public good, which is a Nash equilibrium. Then, no player sends a message and they all choose $z_i = 0$. Also assume that $1/n < \theta_i$ so that everyone can be better off if all agents contribute. With above message and strategy profile any unilateral deviation leads the agent to a non-profitable outcome since $\theta_i < 1$. Yet, a coalition of all the players can deviate to the message profile $\bar{m} = \{n, n, \ldots, n\}$ yielding the outcome $z^{'} = \{1, 1, \ldots, 1\}$. This message profile is obviously a Pareto improvement. Hence, this Nash equilibrium is not a strong mediated equilibrium or a Pareto efficient strategy since every coalition member is strictly better off.

In any case where $\theta_i < \frac{1}{n}\ \forall i$, it is always a dominant strategy not to contribute. Even all agents decide to contribute, everybody is worse off. Thus, we will analyze the cases where $\frac{1}{n} \leq \theta_i\ \forall i$.

An outcome is Pareto efficient if there is no other strategy profile that can improve agents' utilities while not making anybody worse off. Then, assuming that $1/n \leq \theta_i\ \forall i$ everybody contributing to the public good is a Pareto optimal outcome. For some cases, this outcome can be achieved through more than one message profile in a stage game. Yet, not all of these message profiles can be stable against deviations. For instance, we can achieve full participation of the agents (in an n-agent case) with the following two message profiles: $m^{'} = \{2, 2, \ldots, 2\}$ and $m = \{n, n, \ldots, n\}$. But, for $m^{'}$ all individuals have an incentive of unilateral deviation since the other agents still continue to contribute even after an agent deviates to a zero contribution strategy. Hence, that cannot be a candidate for a strong mediated equilibrium. On the other hand, m consists of unexploitable messages and is stable against any will of deviation. Then, using message profile m can yield a strong mediated equilibria.

Proposition 4: Given $1/n \leq \theta_i$ for all i, BCCM constitutes a strong mediated equilibrium where all agents contribute using a message profile with unexploitable messages.

Proof: $m = \{n, n, \ldots, n\}$ is the only message profile where all agents contributes using unexploitable messages. To see that, we need to check if there can be any deviation of a coalition which is profitable. If there is not, BCCM with the message profile m produces a strong mediated equilibrium. With the message m, everybody contributes and a player i gets a payoff of $\theta_i n$. Let $S \subseteq I$ be a coalition of the players and denote S^c for the complement of S. Also let |S| = s. The members of this coalition can deviate to a message profile $m_i^s \in \{2, 3, \ldots, n\}$ or choose their contribution by themselves. Also, message profiles of this coalition's members do not need to be the same. If $m_i^s \leq n$ or $z_i^s = 1$ for all coalition members, then the outcome space is the same where everybody contributes. But, since nobody is better off, it is not a profitable deviation for the members of the coalition.

If some agents deviates to $m_i^s \leq n$ or $z_i^s = 1$ and some deviates to $z_i^s = 0$, then every agent in S^c does not contribute and less than s agents contribute in S. Payoff of the contributing agents in S is, then $u_i^s < \theta_i s$. Since $\theta_i s < \theta_i n$, there cannot be a profitable deviation for this coalition.

If $z_i^s = 0$ for all $i \in S$, then everybody in S and S^c does not contribute. In total, there would be no contribution. In this case, the utility of the agents in S is one, which comes from their initial endowments. Thus, if this utility is less than the utility they get with above message profile m, then a strong mediated equilibrium is reached. Formally, $1 \leq \theta_i n$ needs to hold. Hence, we can conclude that for any θ_i greater than or equal to $1/n$ for all i, BCCM with the message profile $m = \{n, n, \ldots, n\}$ constitutes a strong mediated equilibria.

Intuition is the same as in our mechanism: agents' valuation of the public good must be above some precise level so that provision of the public good can be beneficial for them at some point. Otherwise, at every level of the public good not to contribute becomes more profitable for the agents. Moreover, as we discussed above, full contribution by all agents is a Pareto optimal outcome and hence any deviation from this outcome in accordance with unexploitable message conditions harm any deviating agent.

Knowing that unexploitable messages can create Pareto efficient and strong mediated equilibria, in the next section we are just going to deal with these type of messages that cannot be violated.

3.8.1 Other Pareto optima and strong mediated equilibria

Proposition 5: In the BCCM setting, every Pareto efficient outcome constructed by a message profile with unexploitable messages, given $\theta_i \geq 1/n$, is a strong mediated equilibrium.

Proof: Let there exists a set of players $I = \{1, 2, \ldots, n\}$ with an endowment of one unit. Assume that a player i has a valuation of $\theta_i \in [0, 1)$ of the public good. A Nash equilibrium outcome can be Pareto efficient only if, given θ_i, at most $\lfloor \frac{1}{\theta_i} \rfloor$ players do not contribute and at least $\lceil \frac{1}{\theta_i} \rceil$ players contribute. Here, $\lfloor \frac{1}{\theta_i} \rfloor$ is the largest integer less than or equal to $\frac{1}{\theta_i}$ and $\lceil \frac{1}{\theta_i} \rceil$ stands for the smallest integer greater than or equal to $\frac{1}{\theta_i}$.

Let $S \subseteq I$ be a subset of the players. Also, let $|S| = s$. Assume that only agents that decide to contribute to the public good is the players in S and no other player contributes. So, every player in S^c does not contribute. The corresponding message profile for S need to be $m_S = \{s, s, \ldots, s\}$ to be constructed by unexploitable messages. The strategy profile for S^c is $z_i = 0$. Then for any player i in S, his utility is: $u_i^s = \theta_i s$. On the other hand, every player in S^c gets a payoff of $u_i^{s^c} = 1 + \theta_i s$. For this set-up to be a Pareto efficient outcome there should not be a Pareto improvement over it. Since we know that every agent contributing to the public good is a Pareto optimal outcome and this case offers the highest attainable social payoff in our setting, we need to ensure that deviating to full contribution case is not a Pareto improvement. Yet, for a more general case define $\bar{z}$ to be an outcome where the level of public good is higher than s. As the number of contributors increases, players in S get better off since their utility is now greater than $\theta_i s$, $u_i^S(\bar{z}) > \theta_i s$. For the players in S^c, if the utility provided in $\bar{z}$ is less than the utility they initially get, then there cannot be a Pareto improvement for these players and we can achieve a Pareto efficient outcome. For players in S^c, an outcome $\bar{z}$ can provide at most $\theta_i n$ utility which is possible in full contribution case. Then, we should assure that;

$$
\begin{aligned}
\theta_i n &\leq 1 + \theta_i s \\
n - s &\leq \frac{1}{\theta_i} \\
|S^c| = n - s &\leq \frac{1}{\theta_i} \qquad (3.11)
\end{aligned}
$$

Thus, for all i there cannot be more than $1/\theta_i$ players in the BCCM mechanism that do not contribute in order to have a Pareto efficient outcome. This condition secures that non-contributors can have no improvement on their utilities by any unilateral or group deviation as the total contribution to the public good increases.

Now suppose that an outcome $\underline{z}$ is defined where the total of public good is less than s. Then players in S^c gets worse off because the lower the level of public good, the less utility they get, $u_i^{S^c}(\underline{z}) < 1 + \theta_i s$. So there cannot be a Pareto improvement when the level of public good decreases.

Also, define an alternative outcome z' where the public good level equals s. Considering public good level stays the same, this outcome is only possible when some originally contributors are now non-contributors and some non-contributors now contribute. But, such a case would reduce the payoff of the new contributors as $\theta_i s < 1 + \theta_i s$. Hence, no Pareto improvement is possible when the public good level does not change.

Moreover, we should ensure that every player in S is better by contributing, which is the requirement of individual rationality. If they do not contribute, everybody gets a payoff of one. Then, if $\theta_i s$ is greater than one, we can conclude that for these players there is no profitable deviation by not contributing. So, $1 \leq \theta_i s$ should hold, meaning that

$$\frac{1}{\theta_i} \leq s = |S| \tag{3.12}$$

Hence, for optimality it is also needed that the number of the players contributing must be greater than or equal to $\lceil \frac{1}{\theta_i} \rceil$.

It is important to note that these conditions satisfy only if the message profile consists of unexploitable messages. Since the outcomes are both Nash equilibria and Pareto efficient, they can only be attained through unexploitable messages.

Now, consider strong mediated equilibria. Let there be n players with a valuation of $\theta_i \in [0, 1)$ for the public good. Denote S as the set of contributors and S^c as non-contributors. Also let $|S| = s \leq n$ and $|S^c| = s^c = n - s$. Then, the utility functions are $u_i^s = \theta_i s$ and $u_i^{s^c} = 1 + \theta_i s$.

For a strong equilibrium, there should not be a coalition that can improve their members' payoff. Then, consider a coalition $C \subseteq I$ where $|C| = c \leq n$. If there cannot be any increase in the well-being of this coalition's members, then we have a strong equilibrium.

First, let $C \subseteq S$. If they choose to contribute, there will be no change. If they choose not to contribute, then $u_i^c = 1 + \theta_i(s - c)$. For this not to be an improvement for them, $u_i^c = 1 + \theta_i(s - c) \leq u_i^s = \theta_i s$ should hold. Yielding that, $c \geq \frac{1}{\theta_i}$. Since $s \geq c$, $s \geq \frac{1}{\theta_i}$ should hold.

Now, let $C \subseteq S^c$. If they choose not to contribute, there will be no change. If they choose to contribute, then $u_i^c = \theta_i(s + c)$. For this not to be an improvement for them, $u_i^c = \theta_i(s + c) \leq u_i^{s^c} = 1 + \theta_i s$ should hold. Yielding that, $c \leq \frac{1}{\theta_i}$. Since $s^c \geq c$, more restrictedly $s^c \leq \frac{1}{\theta_i}$ should hold to ensure that no deviation occurs.

At last, assume that $C \nsubseteq S$ or $C \nsubseteq S^c$ so that $C \cap S \neq \emptyset$ and $C \cap S^c \neq \emptyset$. If they choose to contribute, then $u_i^c = \theta_i(s + \bar{c})$, where $\bar{c}$ is the number of agents in the coalition that is originally a non-contributor. Those who are originally contributors are always better off since $u_i^s = \theta_i s \leq u_i^c = \theta_i(s + \bar{c})$. For this not to be an improvement for originally non-contributors, $u_i^c = \theta_i(s + \bar{c}) \leq u_i^{s^c} = 1 + \theta_i s$. Yielding that, $\bar{c} \leq \frac{1}{\theta_i}$. Since $s^c \geq \bar{c}$, more restrictedly $s^c \leq \frac{1}{\theta_i}$ should hold to ensure that no deviation occurs.

If they choose not to contribute, then $u_i^c = 1 + \theta_i(s - \underline{c})$, where $\underline{c}$ is the number of agents in the coalition that is originally a contributor. For this not to be an improvement for originally contributors, $u_i^c = 1 + \theta_i(s - \underline{c}) \leq u_i^s = \theta_i s$. Yielding that, $\underline{c} \geq \frac{1}{\theta_i}$. Since $s \geq \underline{c}$, $s \geq \frac{1}{\theta_i}$ should hold. Those who are originally non-contributors are always worse off since $u_i^{s^c} = 1 + \theta_i s \leq u_i^c = 1 + \theta_i(s - \underline{c})$. So, this coalition cannot choose not to contribute.

Combining all these restrictions we can conclude that a strong equilibrium exists only if, given $\theta_i \geq 1/n$, at most $\lfloor \frac{1}{\theta_i} \rfloor$ players do not contribute and at least $\lceil \frac{1}{\theta_i} \rceil$ players contribute. This proves that every individually rational Pareto efficient outcome of BCCM with unexploitable messages is a strong mediated equilibrium.

3.8.2 Examples for Pareto optima in BCCM

Now, we present some examples for Pareto efficient outcomes in BCCM setting we discussed in section 3.8.1. We check the conditions to have a Pareto efficient outcome for different cases.

Example 3: Consider a twenty-agent public good game. Let $\theta_i = 0.5$ for all i. Then, in order to have a Pareto efficient outcome there should be at least 2 contributing and at most 2 not contributing agents. Hence, to achieve both of these properties at least there should be 18 agents contributing. Consider the message profile $\bar{m} = \{18, 18, \ldots, 18\}$ for 18 of the agents where all of them contribute. Also suppose that the last two agents do not send a message and have the strategies $z_{19} = 0$ and $z_{20} = 0$ so that they do not contribute. These messages are also unexploitable. If any contributing agent deviates to a message $m_i \leq 18$, outcome will be the same and no one will be better off. If any of them choose $m_i \geq 19$ or $z_i = 0$, they are worse off. For the last two agents contributing makes them worse off. And for any coalition of the players, the coalition can make at most a utility of 10 which the last two agents now have. Hence, no Pareto improvement is possible for this Nash equilibrium profile.

An example where individuals have different valuations for the public good should be persuasive.

Example 4: Suppose that there are 20 agents and six of them value the public good as $\theta_i = 0.25$ while the remaining 14 has a valuation of $\gamma_i = 0.5$. For θ_i valuers, there must be at least four contributors and at most four non-contributors. Considering agents with γ_i valuation, at least two agent should contribute and at most two do not. Combining all these requirements, we can conclude that there should be at least 18 contributing agents and at most 2 non-contributing. Using unexploitable messages, a message profile $\hat{m} = \{18, 18, \ldots, 18\}$ for eighteen of the agents and a strategy profile $z_{19} = 0$ and $z_{20} = 0$ for the other agents satisfy the conditions. No individual deviation is possible, yet consider a twenty-agent coalition. Then, θ_i players get 5 payoff as γ_i players earn 10. But, for the above message profile θ_i non-contributors have a payoff of 5.5 so that any coalition makes them worse off. Thus, this message profile is also a Pareto efficient strategy.

CHAPTER 4

EXPERIMENTAL DESIGN AND PROCEDURES

All sessions of the experiment is conducted at the economics laboratory of Boğaziçi University, İstanbul during May and November, 2018. All subjects were undergraduate students and the registration was organized with ORSEE (Greiner, 2015) and the experiment was conducted using z-Tree (Fischbacher, 2007). The experiment had 8 sessions each with 12 participants. Approximately 46 percent of our 96 subjects were female. At the beginning of the experiment, three groups of four subjects were formed and each group played the game repeatedly for ten periods. The groups were set up randomly at the beginning of the first period and at all periods, the members of the groups were held the same. Each participant was settled randomly and separately so that no communication or interaction was possible.

Before each session, all participants were informed about the process of the game, endowments, individual valuations and the payoff function. After the presentation of the instructions on the computer screen, sessions were followed by questions for understanding. Subjects had to answer each question correctly in order to proceed. After the completion of this stage, the main treatment started. After each period, each player could check the individual and group decisions, as well as their earnings. At the end of the sessions, participants were asked to fill a survey about their personal characteristics. English translation of experimental instructions, the control questions and some screenshots from the experiment can be found in Appendix A. Ethics committee approval is also presented in Appendix B.

In the game, participants basically decide to how much to invest in a group project and how much to keep with themselves. Each participant starts with 20 points as their endowments. Every point kept gives a payoff of one to the participant whereas each point spent for the group project returns 0.4 payoff to all members of the group. Players were asked to make two decisions on the same screen: (i) whether to participate the conditional commitment agreement, and (ii) how much to invest in case an agreement does not occur. Players make their decisions simultaneously and independently. Among 8 sessions conducted, four of them are planned to represent Full Commitment case whereas others were designed to investigate Half Commitment case. If all members of a group decide to use the conditional commitment agreement, then everyone invests 20 points in the project in Full Commitment treatment and 10 points in Half Commitment treatment. If at least one member decide not to use it, then each player invests the amount he stated. Based on actions they can take, payoffs are determined as follows:

Payoff = (20 - individual investment in the group project) + 0.4 * (total investment in the group project)

After each period players could see how many members of their group participated to the agreement, how much he and the other members invested, payoff they earned at that period and total payoff until that period. In another screen, they could see these information by individual levels, yet the order of the members was randomized to ensure that their decisions could not be affected.

Each session lasted nearly 40 minutes. Subjects were paid in cash and privately at the end of the each session. Points they earned in the game were converted into Turkish Liras (TL) as 10 points = 1 TL. Participants were also paid 10 Liras in addition to their earnings as the participation fee. On average, players earned slightly above 37 Liras with the addition of participation fee. In ’full contribution’ case an average of 39.7 Liras were earned, meanwhile in ’less than full contribution’ case participants made an earning of 34.8 Liras on average.

CHAPTER 5

DATA AND RESULTS

Subjects in the experiment were asked to decide on two issues: whether to choose the mechanism and how much to invest in the public good in case no agreement emerges. We will then try to analyze the data comes from these variables. We call them approval for using the mechanism or commitment to the mechanism and chosen contribution level. First, we will note down the general statistics and continue with presenting the regressions we run to find the determinants of these variables.

Figure 1 shows the average approval rate in two separate treatments. It can be seen that, in both treatments, at least 80% of the participants chose to use the mechanism. The average is higher in full commitment treatment likely because the agents can achieve the highest payoff in the game if they all agree to use the mechanism. On the other hand, in the half commitment treatment agents cannot guarantee that they can make the highest profit. Time trend of the decisions also differs in the treatments. When the commitment level is higher, approval rate increases across periods. For lower commitment levels, the approval rate fluctuates. Before the fifth period, there is an explicit decrease in the usage of mechanism whereas after that period approval rate recovers and again reaches its initial levels.

Next, we need to look how approval messages participants sent are converted into an agreement in their group. As Figure 2 suggests groups in full commitment treatment mostly managed to reach an agreement. Considering the third period and onwards, we can conclude that almost all approval messages lead to an agreement in the groups. As we mentioned earlier, participants could not communicate during the experiment. Thus, approval messages in a given period cannot affect any approval decision of another agent in that period. Yet, previous messages may affect that decision. We are intend to find out that effect later in the regression we ran. As opposed to full commitment treatment, groups in half commitment treatment have

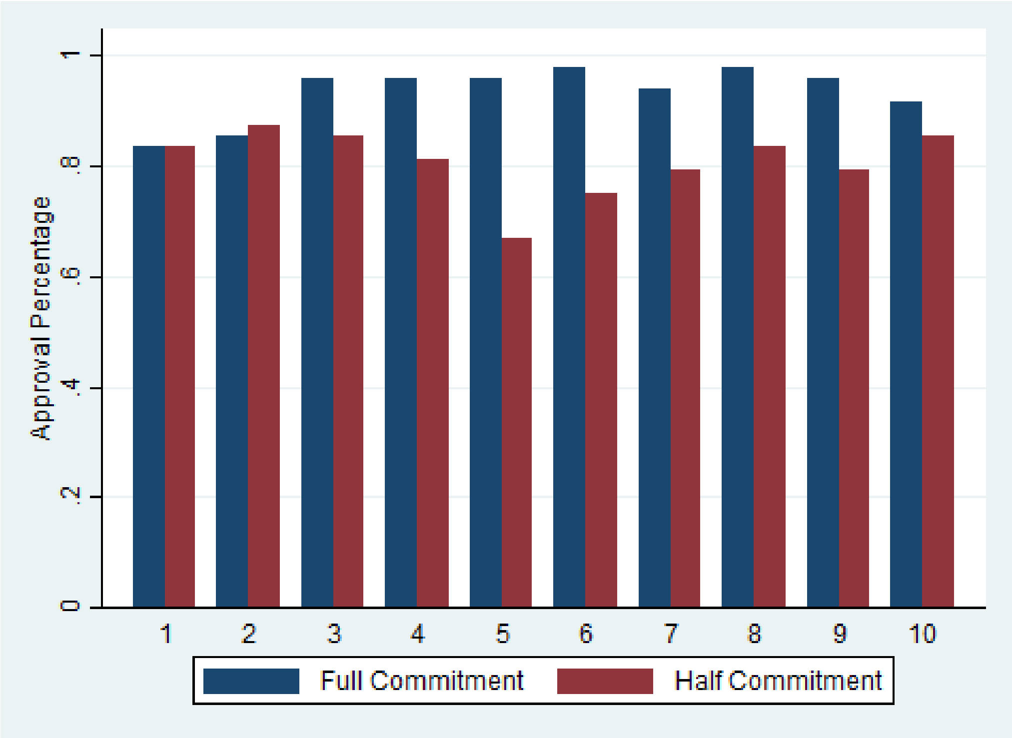

Figure 1: Approval for using the mechanism

difficulty in reaching an agreement considering the rate of approval messages. Yet, 47% of the time they manage to have an agreement as shown in Table 1. The number of agreements made in every period is also shown in this table. There were 120 possible agreements for each treatment and half commitment groups manage to have 56 agreements while in the full commitment case they achieve to reach 93 agreements.

In Appendix C, we add additional figures for group level agreement data. Figure C1 shows the agreement rate of each group in the full commitment treatment while Figure C2 stands for the half commitment case. 10 groups in full commitment treatment mostly managed to have an agreement (agreement rate higher than 50%). Yet, the number of groups that mostly managed to reach an agreement is only 5 in half commitment treatment. We can conclude from that lower commitment levels (the prescribed amount of commitment in the mechanism) lead to fewer agreements in groups.

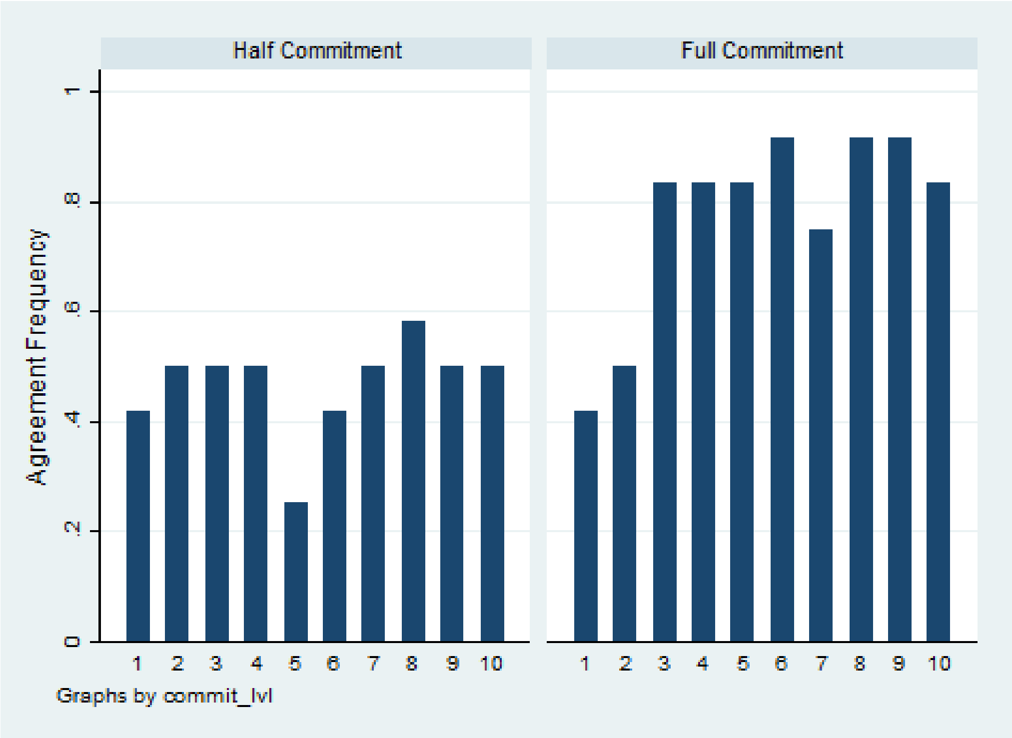

Figure 2: Agreement frequency in groups

Now, we will try to examine the data of chosen contributions. Participants were asked to state the level of contribution they would like to make in the public good if at least one member of their group choose not to send an approval message so that no agreement is reached through the mechanism. So, these contribution levels are not the levels settled after they make their decisions. Checking Figure 3 that shows the average chosen contribution levels in periods, full commitment groups tend to limit their chosen contributions at lower levels compared to half commitment groups. This comparison is valid considering both subgroups in each treatment. We divide participants into two groups: approval message senders and disapproval message senders. In the full commitment treatment, participants who approve to participate in the agreement set slightly higher contribution levels than the ones that do not approve. In contrast with this difference, disapproval message senders in half commitment treatment determined much higher contribution levels as opposed to approval message senders. Especially between third period and seventh period they intended to make higher contributions than the predetermined commitment level 10. These choices may come forward due to the intention of achieving higher payoff levels.

Table 1. Number of Agreements in Groups

	Half Commitment		Full Commitment	
Period	No Agreement	Agreement	No Agreement	Agreement
1	7	5	7	5
2	6	6	6	6
3	6	6	2	10
4	6	6	2	10
5	9	3	2	10
6	7	5	1	11
7	6	6	3	9
8	5	7	1	11
9	6	6	1	11
10	6	6	2	10
All	64	56	27	93
Percentage	53%	47%	23%	77%

Agents can get a payoff of 26 at most if an agreement occurs through the mechanism. But, rather than approving the usage of mechanism of half commitment, agents could make more profits if they all make investments higher than 10. Figure 4 also strengthens these findings. Most participants frequently chose lower contributions levels, especially zero contribution. Yet, in half commitment treatment, participants who did not attend to make an agreement set their chosen contribution levels as 20 as frequently as 0. Considering efficient level is reached as all agents invest all their endowments in the public good, this figure clearly points out that the intention of those participants was to achieve a Pareto improvement. We can also note down that for all groups chosen contribution levels decrease in last periods.

We provide the average chosen contribution levels within the groups in Appendix C. Figure C3 and Figure C4 shows the average chosen contribution levels of full commitment groups and the average chosen contribution levels of half commitment groups, respectively. All groups in full commitment treatment chose

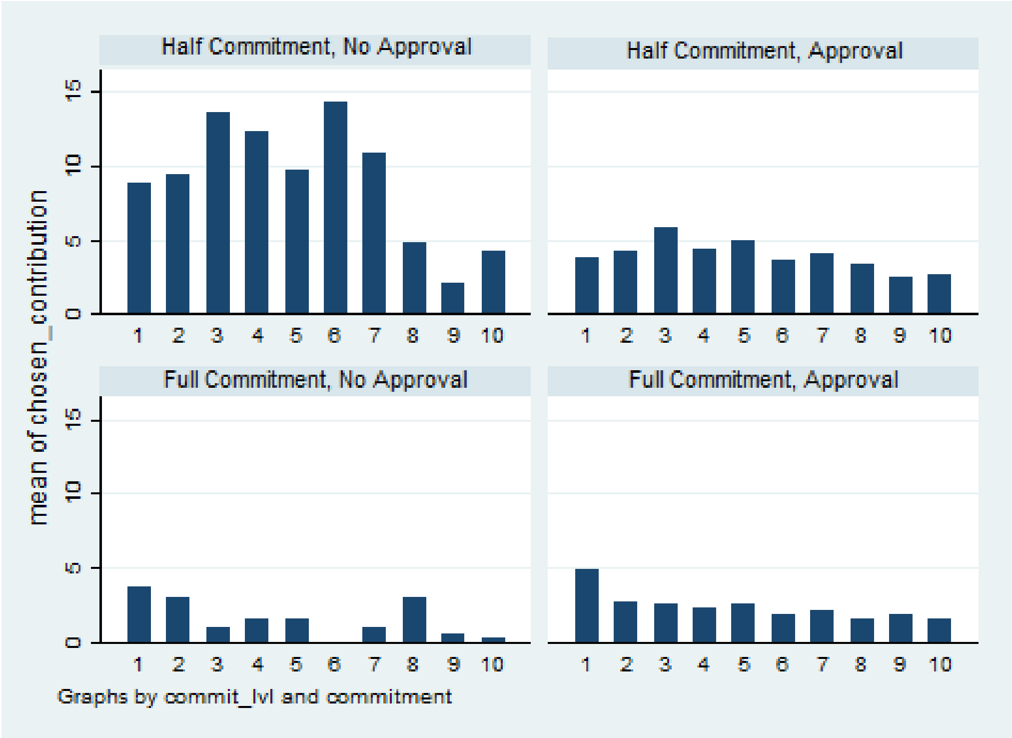

Figure 3: Chosen contribution decisions across periods

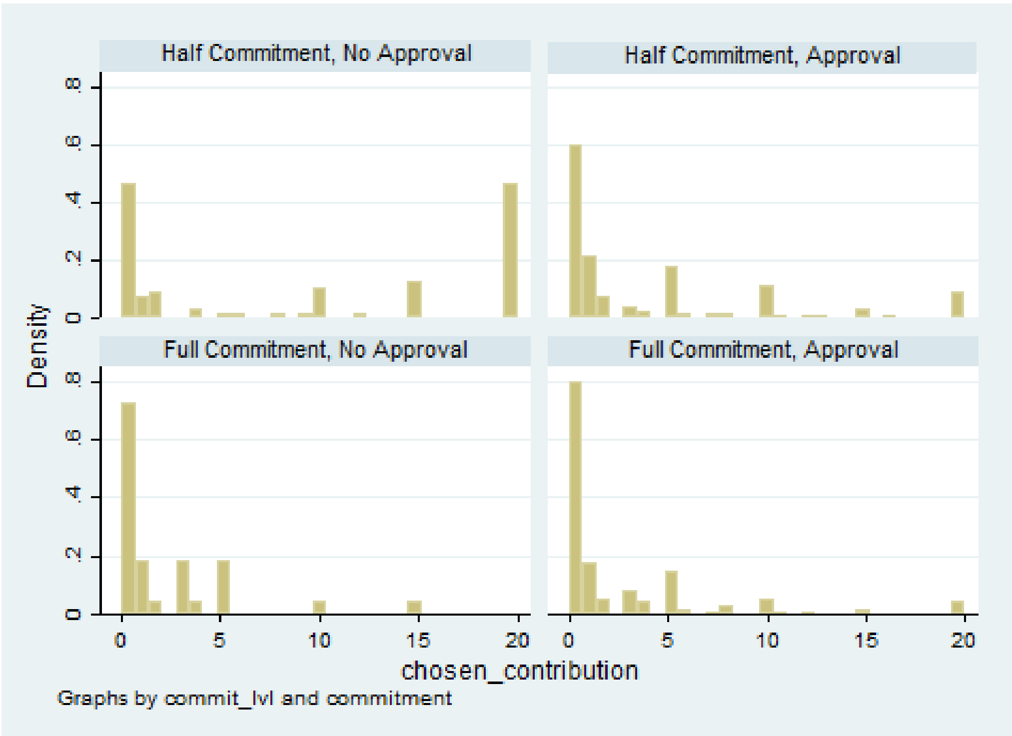

Figure 4: Frequency of chosen contribution levels

contribution levels lower than six on average. Only in one group in half commitment treatment the mean of the chosen contribution levels was above 10.

Figure 5 exhibits the frequency of realized contributions. Since most of the participants approve to use the mechanism and this yields an agreement in the groups, approval message senders mostly end up with contributing the predetermined commitment level in both treatments. Agents that do not participate in the agreement usually free-ride by not contributing at all as expected. Because of their chosen contributions we mentioned, some agents in the half commitment treatment end up with 20 contribution.

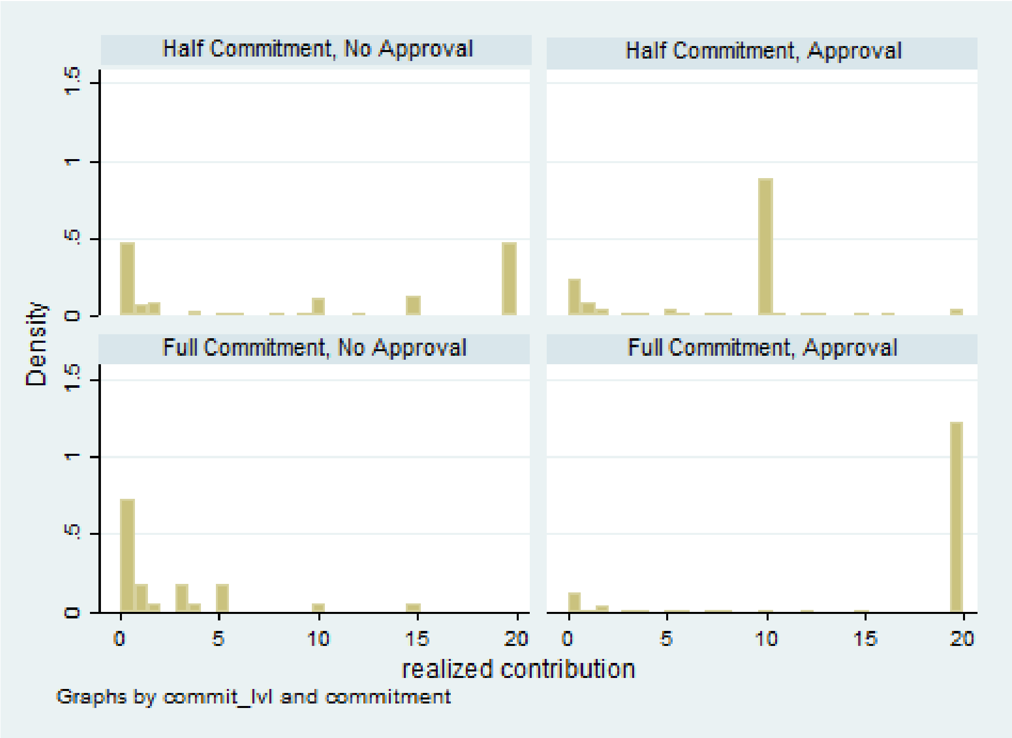

Figure 5: Frequency of realized contribution levels

In theoretical analysis, we point out that strong mediated equilibrium is achieved if all agents choose to use the mechanism. Yet, chosen contribution levels may provoke other agents to deviate and free-ride in a dynamic setting if they are above zero. Thus, an unexploitable message, as in Reischmann and Oechssler (2018), in our mediated game would be to approve the usage of the mechanism and set chosen contribution level to zero. Now, we would like to see how often the participants choose to use unexploitable messages. Figure 6 reveals that the usage of

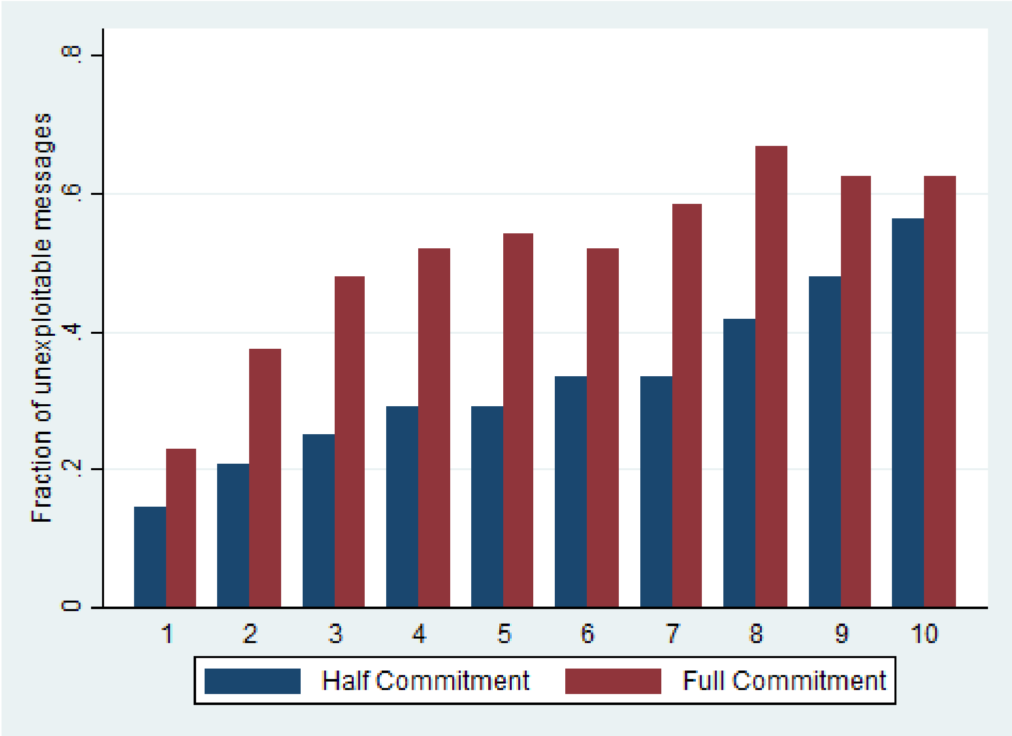

Figure 6: Fraction of unexploitable messages

unexploitable messages increases across periods for both treatments and reaches around 60% in the last period. In addition, agents in the full commitment case use these messages more often. That is because unexploitable messages in this treatment can yield the highest payoff possible in the game.

To determine the determinants of our focus variables, we run a series of regressions. Table 2 yields the results for commitment (approval) decision. Commitment is a binary variable in our data and takes values 0 for disapproval and 1 for approval of participating the agreement. Thus, we run a series of probit and logit regressions. Since the results of these regressions does not differ in statistical significance, we here present the results for probit regressions. Our regression equation is as follows:

$$
\begin{aligned}
Commitment_t = {} & \beta_{0t}Constant_t + \beta_{1t}(Full\ Commitment)_t + \beta_{2t}Period_t \\
& + \beta_{3t}Commitment_{t-1} + \beta_{4t}(Group\ Agreement)_{t-1} \\
& + \beta_{5t}(Chosen\ contribution)_{t-1} + \beta_{5t}(Control\ variables) + u_t
\end{aligned}
$$

We used a number of independent variables for these probit regressions. The main variables are listed below while control variables we used are presented in Table D1 and Table D2 in Appendix D. It should also be noted that control variables does not change over periods.

Full Commitment: a dummy variable which takes the value 1 for full commitment treatment

Period: the current period in the game

Commitment in t-1: a dummy variable for one period lagged commitment decision of the agent

Group Agreement in t-1: a dummy variable for one period lagged agreement in the group

Chosen contribution in t-1: one period lagged chosen contribution of the agent

In all regressions, the dummy for full commitment treatment remains highly significant. As we discussed earlier, an agreement reached through our mechanism yields the highest payoff possible and there is no cost for using it. This fact encourages the participants to use it. Yet, since half commitment treatment cannot guarantee that payoff, agents may choose not use it. The current period does not provide any explanation to commitment decision. Lagged variables for commitment and chosen contribution are statistically significant whereas lagged agreement does not contribute to the analysis. Then, we can conclude that previous decisions of the individual affects his current decisions for commitment, but group decisions seem to have no effect on them. This result may arise from the fact that participating the conditional agreement is the dominant strategy and yet it is costless. So, apart from the decisions other members made an agent could commit to the agreement and wait for others to participate. Note that previous commitment decision has a positive effect on the current one. This shows that agents keep their commitment decisions constant over time. Nevertheless, less chosen contribution levels in the previous period leads agents to use conditional commitment agreement more likely. This relation corresponds to the increasing usage of unexploitable messages. As agents move on to further periods, they approach to the dominant strategy and begin to use unexploitable messages.

Table 2. Determinants of Commitment

	(1) commitment	(2) commitment	(3) commitment	(4) commitment
Full Commitment	0.641***	0.511**	0.518***	0.499**
	(0.182)	(0.192)	(0.139)	(0.177)
Period	0.0189	0.0199	-0.00814	-0.00723
	(0.0259)	(0.0264)	(0.0273)	(0.0288)
Commitment in t-1			1.035***	0.940***
			(0.228)	(0.219)
Group Agreement in t-1			0.00969	-0.00731
			(0.160)	(0.142)
Chosen contribution in t-1			-0.0327**	-0.0315**
			(0.0121)	(0.0109)
Constant	0.760***	1.278	0.335	0.681
	(0.191)	(0.953)	(0.266)	(0.698)
Controls	No	Yes	No	Yes
N	960	960	864	864

Standard errors are clustered at group level and reported in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

OLS regression results in Table 3 give the estimated effects on the chosen contribution decision where independent variables are full commitment dummy, commitment dummy, the interaction of full commitment dummy and commitment decision, the current period and control variables listed in Table D1 and Table D2 in Appendix D. As mentioned above, control variables does not change over periods.

$$\begin{aligned}(Chosen\ contribution)_t =& \beta_{0t} Constant_t + \beta_{1t}(Full\ Commitment)_t \\ &+ \beta_{2t} Commitment_t \\ &+ \beta_{3t}(Full\ Commitment * Commitment)_t \\ &+ \beta_{4t}(Period)_t + \beta_{5t}(Control\ variables) + u_t\end{aligned}$$

Also in this regression the full commitment treatment shows significant effect on agent's decision. Being in the full commitment treatment causes participants to set considerably lower chosen contribution levels. Making contributions without the mechanism may cause payoff loss, to avoid that agents choose low contribution levels. This amount is lower in the full commitment treatment because agents could make higher profits using the conditional agreement in that treatment. In half commitment treatment some agents try to achieve a Pareto improvement by contributing more individually. Figures we examined above proves this argument. Agents who approve the use of conditional commitment agreement determines lower contribution levels. The significance of the commitment variable and its negative value demonstrate this relation. The results of interaction variable comes from the fact that most contributors are the disapproval message senders in half commitment treatment and the least are the agents who approve the agreement in the full commitment treatment. The current period also has a small, negative but significant effect on the contribution decision. As we have seen from the above figures, participants are lowering their chosen contribution levels as they move forward in periods.

Table 3. Determinants of Chosen Contribution

	(1) chosen contribution	(2) chosen contribution
Full Commitment	-7.481**	-6.837**
	(2.178)	(2.210)
Commitment	-5.337**	-5.093**
	(1.737)	(1.711)
Full Commitment*Commitment	5.965**	5.682*
	(1.998)	(2.169)
Period	-0.298***	-0.297***
	(0.0743)	(0.0756)
Constant	10.87***	4.451
	(2.126)	(4.101)
Controls	No	Yes
N	960	960

Standard errors are clustered at group level and reported in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

CHAPTER 6

CONCLUSION

Knowing the fact that voluntary contribution mechanism cannot yield Pareto optimal outcomes, introducing the conditional commitment mechanism we try to achieve more desirable and dependable outcomes in the original public good game. Our theoretical analysis suggests that in an environment where people adequately value the public good, using conditional commitments, we can reach Pareto optimal outcomes that are strong mediated equilibria. These equilibria ensures that no player or a coalition of the players would prefer to deviate from these equilibria. Thus, it is possible to reach efficient levels of public good both in static and dynamic settings. The more the people's valuation of the public good the more possible it is to reach efficient outcomes. As long as people know that investing in public good returns a valuable income, even if the proportion is less than one, they become more ambitious to utilize our conditional commitment mechanism so that they can benefit collective contribution. Besides, we observe that as the conditional commitment level decreases, the conditions on having a strong equilibrium becomes tighter. Hence, it prevents us to achieve efficient levels.

Experimental analysis supports our theoretical findings on the conditional commitment mechanism. As long as a strong mediated equilibrium exists, participant groups, using the mechanism, manage to reach that equilibrium at some point. While participants proceed to next periods, the frequency of sending consent on the usage of conditional commitment mechanism increases. This increase becomes sharper if the commitment level rises. Also, we can conclude that increased commitment levels boost the percentage of the outcomes that yield an agreement. Assuming full commitment treatment, participants who send approval messages are tend to have higher chosen contribution levels. On the other hand, with the half commitment treatment some participants who do not send approval messages becomes more eager to increase their contribution levels even higher than the predetermined level of commitment. This attitude may come from the appetite for having more optimal and beneficial outcomes since half commitment cannot yield a strong equilibrium.

Moreover, our regression analysis suggests that commitment decisions depend on the consent sent in the previous period, chosen contribution level in the previous period and strongly on whether having a full commitment treatment. Contribution decisions, meanwhile, are highly negatively affected by the full commitment treatment. This shows that full commitment agreements lead individuals to manage the optimal through our conditional commitment mechanism. While the current period appears to be ineffective on their commitment decisions, chosen contribution levels happen to decrease in later periods.

APPENDIX A

EXPERIMENTAL INSTRUCTIONS AND SCREENSHOTS

The instructions below are translated from those used in Full Commitment treatment. The instructions from the other treatments are similar and available upon request.

General Information:

You are going to attend an experiment that studies how individuals make decisions in certain circumstances. If you carefully follow the instructions, you could earn a significant amount of money based on your and other participants' decisions. After the experiment, your gain will be paid in cash.

You cannot contact with anybody during the experiment. If you have any questions, please raise your hand. If you do so, we will answer your questions privately. Any violation of this rule requires you to be eliminated from the experiment.

During the experiment, we will use points instead of TL. So, all of your earnings will be calculated in terms of points. At the end of the experiment, total amount of points you earn will be converted to TL according to the following rate:

1 point = 10 Kurus

At the end of the experiment, because of your participation to the experiment, you will also gain an extra 10 TL in cash in addition to your whole winnings.

The experiment consists of 10 separate periods. Participants will be divided into groups and each group will include 4 members. Thus, you will form a group with other 3 participants. Group members will be held the same for all 10 periods.

We will explain the game in detail in the following sections.

Decision Phase:

At the beginning of each period, participants will be given 20 points. We call it the endowment of the participant. Mainly, you will decide how many points to keep with yourselves and how many points to invest in the group project.

Every point you keep will be yours as itself. On the other hand, each point invested in the group project will bring in 0.4 points to you and each member of the group.

We expect you to make 2 decisions in the same screen.

1) Your decision about whether you approve the conditional commitment agreement

2) Your decision about how much to invest in the project in case conditional commitment agreement is not accepted.

If all members of your group approve the conditional commitment agreement, then you will all contribute 20 points each to the project. So, you will invest all your endowments in the project.

If at least one member of the group does not approve, then every member will contribute the amount they have chosen.

Group members will make their decisions simultaneously and independently without seeing others' decisions.

Earnings:

Your income in a period in terms of points is calculated as follows:

(20 - individual investment in the group project) + 0.4 * (total investment in the group project)

Each member of the group earns the same amount of income from the project. For example, assume that every member of the group approves the conditional commitment agreement. Then, everyone will invest 20 points each and the total amount of investment will be 80. In this case, each member of the group will gain 0.4*80 = 32 points.

Now, assume that the conditional commitment agreement is not approved and group members make a total investment of 60 points. In that case, each member will earn 0.4*60 = 24 points.

Every point you keep with yourselves will earn 1 point to you. On the other hand, if you invest the same amount of points in the project, the total amount of invested will increase 1 point. The income you earn from the project will also increase 0.4*1 = 0.4 points. Yet, this will also increase the income of other members as 0.4 points which accordingly increases the total income group members earn about 1.6 points (16 Kurus).

So then, your investment in the group project will increase the earnings of the other members. On the other hand, every point other members invest will also increase your income. Each point invested by a group member will make you earn 0.4*1 = 0.4 points.

Enlightenment:

After all group members make their decisions, in the following screen you can check the number of the group members who approve the conditional commitment agreement, the amount of contribution you and the other group members make, your earning in that period and your total earning including the previous periods.

After that screen, similar information will be displayed at individual level for all members of the group. Your contribution level will be displayed in blue in the first column while other members' investment level will be shown randomly in the remaining three columns. For instance, the investment level in the second column will generally show the choice of a different member in each period. This setting also applies to other columns.

Control Question - 1:

Now, we will ask you some questions. You need to answer them correctly in order to proceed. We remind you the calculation of your income below so that you can use while you answer the questions.

Your income = (20 - individual investment in the group project) + 0.4 * (total investment in the group project)

Every group member has an endowment of 20 points. If every member rejects the conditional commitment agreement, how much income will you earn in that period?

Answer = 20

Control Question - 2:

Your income = (20 - individual investment in the group project) + 0.4 * (total investment in the group project)

Suppose that you approve the conditional commitment agreement and choose to invest 0 points in the project in case the agreement is not approved. Moreover, suppose that the other 3 group members also approve the agreement, thus the agreement is approved.

In the above mentioned case, how many points will you invest in the project?

In the above mentioned case, how many points will the group members (including you) invest in the project in total?

In the above mentioned case, how many points will you earn in total?

Answers = 20, 80, 32, respectively

Control Question - 3:

Your income = (20 - individual investment in the group project) + 0.4 * (total investment in the group project)

Assume that one or more members of the group rejects the contribution agreement and thus the agreement is not approved. You choose to invest 1 point in case the agreement is not approved while the other members choose to invest 2, 3 and 4 points, respectively.

In the above mentioned case, how many points will you invest in the project?

In the above mentioned case, how many points will the group members (including you) invest in the project in total?

In the above mentioned case, how many points will you earn in total (consider the amount you do not invested and keep for yourself)?

Answers = 1, 10, 23, respectively

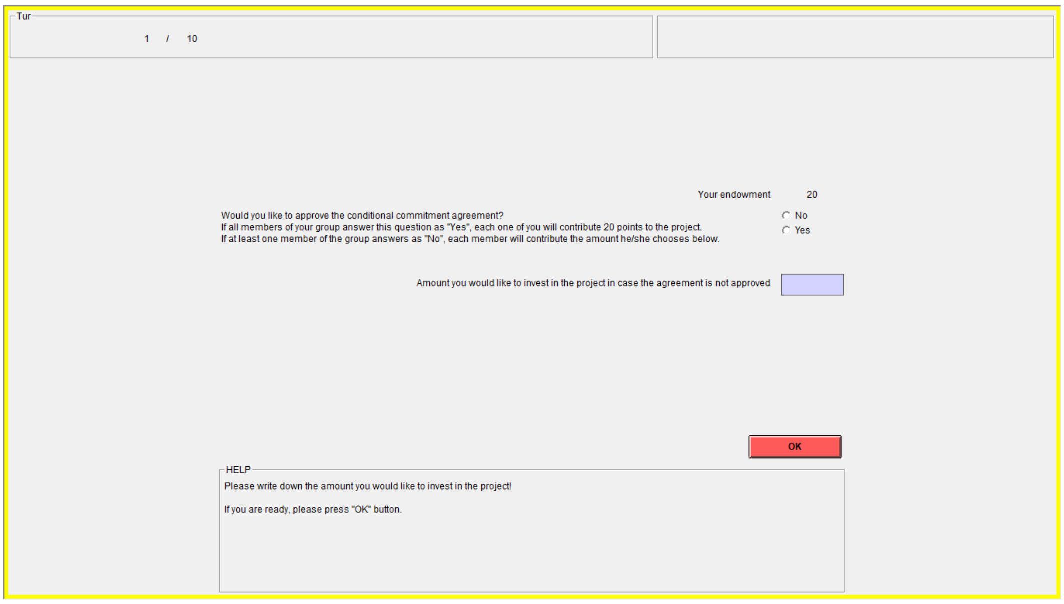

Figure A1: Screenshot of the experiment (decision screen)

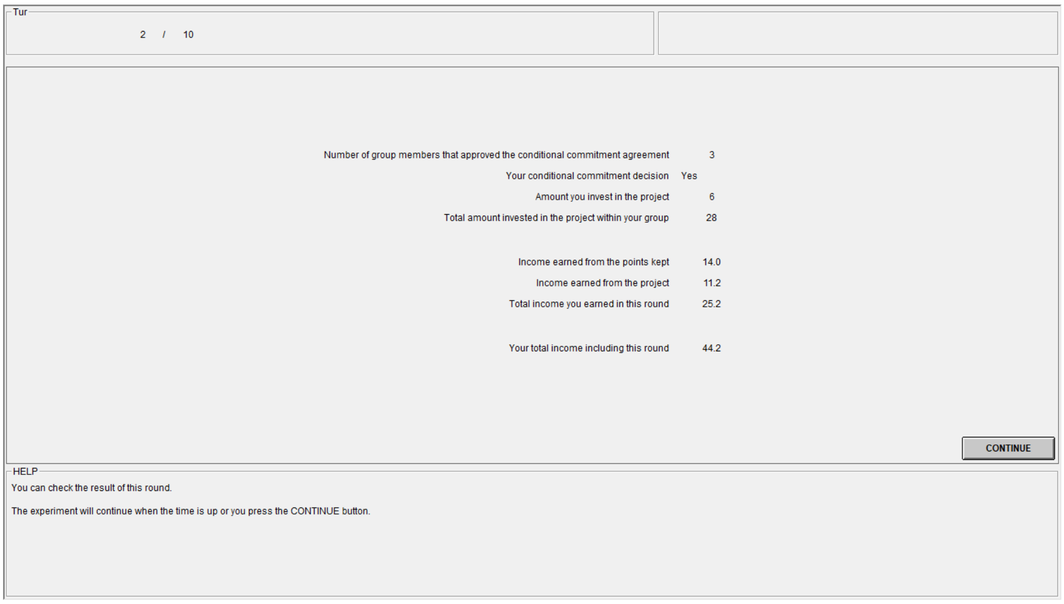

Figure A2: Screenshot of the experiment (check screen)

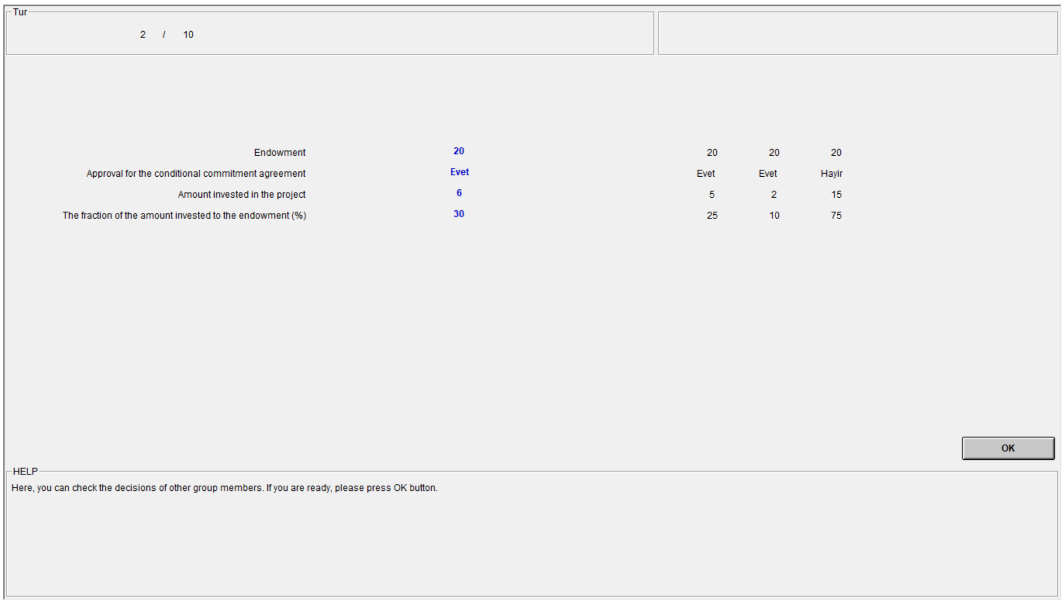

Figure A3: Screenshot of the experiment (individual level check screen)

APPENDIX B

ETHICS COMMITTEE APPROVAL

T.C. BOĞAZİÇİ ÜNİVERSİTESİ
İnsan Araştırmaları Kurumsal Değerlendirme Kurulu (İNAREK)

28.12.2017

Doç. Dr. Mehmet Yiğit Gürdal
Boğaziçi Üniversitesi, Ekonomi Bölümü
34342 Bebek / İstanbul
mehmet.gurdal@boun.edu.tr

Sayın Araştırmacı,

"Eşzamanlı ve Ardışık Oyunlarda İşbirliği, Koordinasyon ve Refah" başlıklı projeniz ile yaptığınız Boğaziçi Üniversitesi İnsan Araştırmaları Kurumsal Değerlendirme Kurulu (İNAREK) 2017/62 kayıt numaralı başvuru 18.12.2017 tarihli ve 2017/6 sayılı kurul toplantısında incelenerek etik onay verilmesi uygun bulunmuştur.

Saygılarımızla,

görevli

Doç. Dr. Arzu Çelik Fuss (Başkan)
Fen-Edebiyat Fakültesi
Moleküler Biyoloji ve Genetik Bölümü
Boğaziçi Üniversitesi, İstanbul

Doç. Dr. Özgür Kocatürk (Üye)
Biyo-Medikal Mühendisliği
Boğaziçi Üniversitesi, İstanbul

Doç. Dr. Özlem Hesapçı (Üye)
İktisadi ve İdari Bilimler Fakültesi
İşletme Bölümü
Boğaziçi Üniversitesi, İstanbul

Prof. Dr. Fatoş Gökşen (Üye)
Fen Edebiyat Fakültesi
Sosyoloji Bölümü
Koç Üniversitesi, İstanbul

Yrd. Doç. Dr. Mine Göl Güven (Üye)
Eğitim Fakültesi,
İlköğretim Bölümü
Boğaziçi Üniversitesi, İstanbul

APPENDIX C

FIGURES FOR GROUP LEVEL DATA

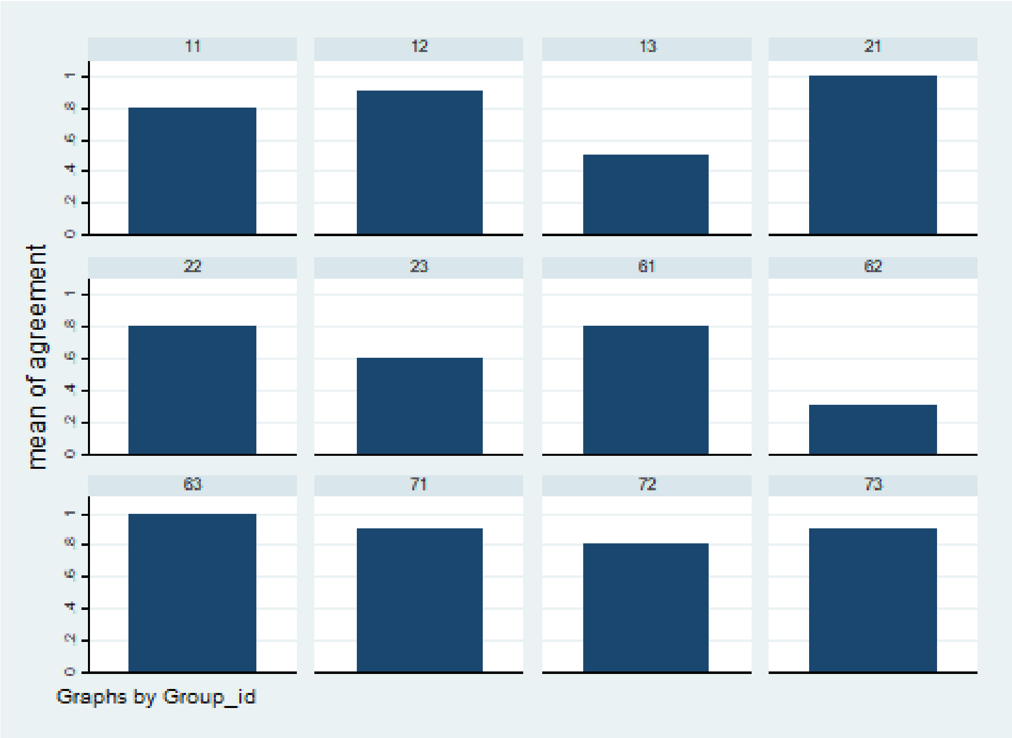

Figure C1: Agreements by groups in full commitment treatment

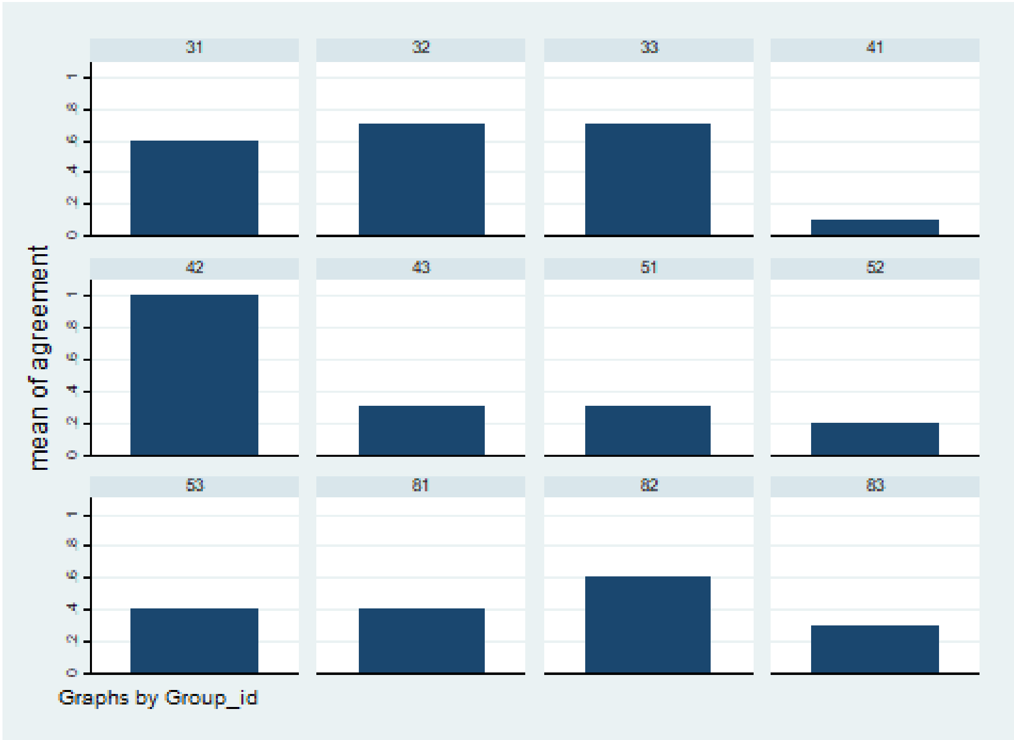

Figure C2: Agreements by groups in half commitment treatment

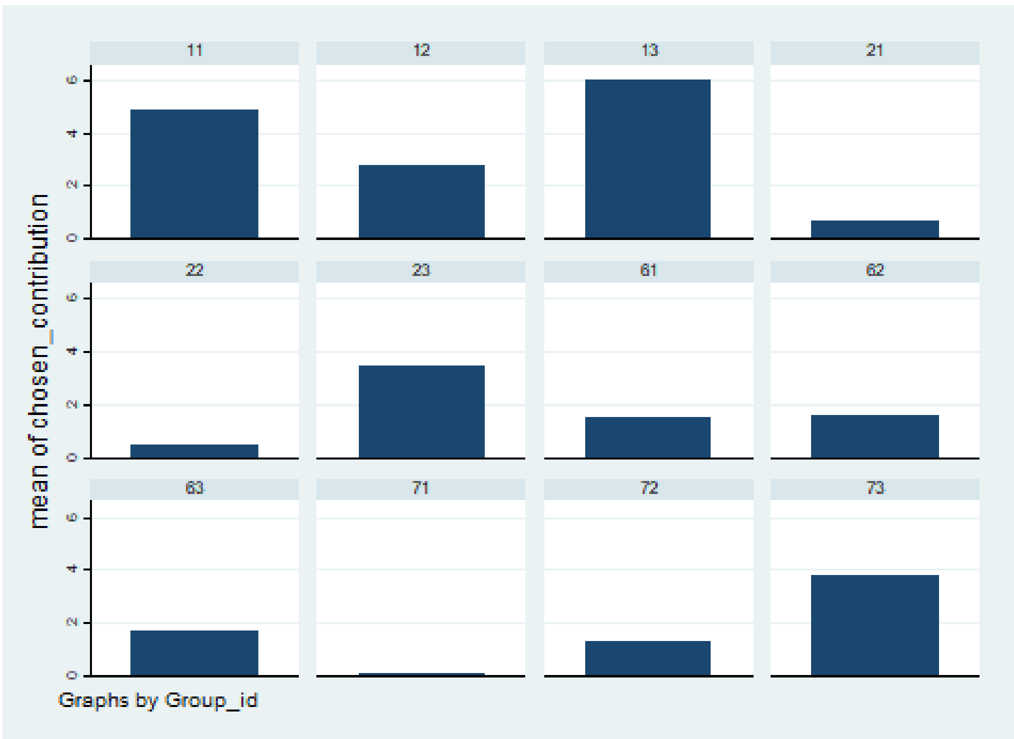

Figure C3: Chosen contribution levels by groups in full commitment treatment

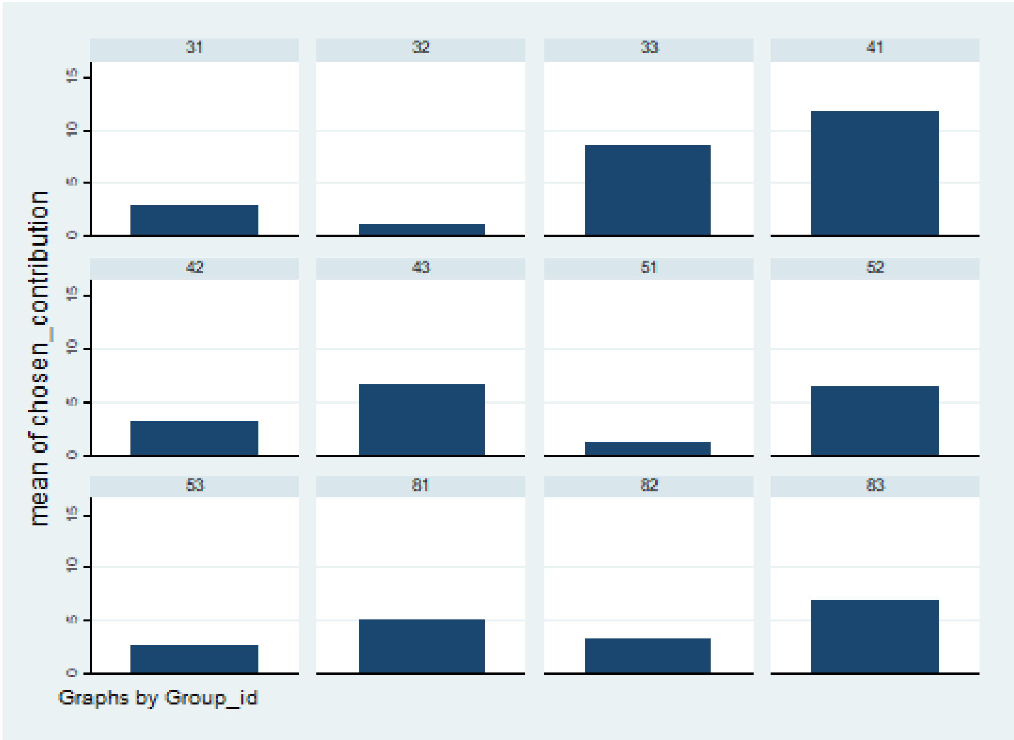

Figure C4: Chosen contribution levels by groups in half commitment treatment

APPENDIX D

CONTROL VARIABLES

Table D1. Ranges and Definitions for Control Variables Used in the Regressions (1)

Variable	Range	Definition
Age	$[18, 30]$	age of the subject
Male	$0/1$	1 if subject indicates gender as male
Living	$[0, 3]$	0 if in dormitory, 1 if with family, 2 if with friends, 3 if alone
Number of Siblings	$[0, 9]$	number of siblings of the subject
Number of Older Siblings	$[0, 9]$	number of older siblings of the subject
Trust	$0/1$	response to general trust question: "Generally speaking, would you say that most people can be trusted or that you need to be very careful in dealing with people?"
Risk Appetite	$[0, 10]$	response to general risk question: "How willing are you to take risks in general?" (0 lowest -10 highest)
Civic 1	$[1, 10]$	claiming government benefits to which you are not entitled
Civic 2	$[1, 10]$	avoiding a fare on public transport
Civic 3	$[1, 10]$	cheating on taxes if you have the chance
Civic 4	$[1, 10]$	claiming the money found in a street
Civic 5	$[1, 10]$	not reporting an accidentally made damage to a parking car

Table D2. Ranges and Definitions for Control Variables Used in the Regressions (2)

Variable	Range	Definition
Major	$[0, 2]$	2 if economics, 1 if international relations or international trade, 0 otherwise
Number of Economics Courses	$[0, 4]$	number of economics courses taken by the subject, censored at 4.
Friends	$[0, 12]$	number of people known in the session
Member	$0/1$	membership to a club, political party, foundation, etc.
Rely	$[0, 10]$	reliability of the information subject provided

REFERENCES

Admati, A., & Perry, M. (1991). Joint projects without commitment, *The Review of Economic Studies*, 58(2), 259-276.

Compte, O., & Jehiel, P. (2003). Voluntary contributions to a joint project with asymmetric agents, *Journal of Economic Theory*, 112(2), 334-342.

Fischbacher, U. (2007). z-Tree: Zurich Toolbox for Ready-made Economic Experiments, *Experimental Economics*, 10(2), 171-178.

Greiner, B. (2015). Subject pool recruitment procedures: organizing experiments with ORSEE, *Journal of the Economic Science Association*, 1(1), 114–125.

Kalai, A. T., Kalai, E., Lehrer, E., & Samet, D. (2010). A commitment folk theorem, *Games and Economic Behavior*, 69(1), 127-137.

Marx, L., & Matthews, S. (2000). Dynamic voluntary contribution to a public project, *The Review of Economic Studies*, 67(2), 327-358.

Monderer, D., & Tennenholtz, M. (2009). Strong mediated equilibrium, *Artificial Intelligence*, 173(1), 180-195.

Reischmann, A., & Oechssler, J. (2018). The Binary Conditional Contribution Mechanism for public good provision in dynamic settings - Theory and experimental evidence, *Journal of Public Economics*, 159, 104-115.

Tennenholtz M. (2004). Program equilibrium, *Games and Economic Behavior*, 49(2), 363-373.

Varian H. R. (1994). Sequential contributions to public goods, *Journal of Public Economics*, 53(2), 165-186.