The Role of Information Structure on Cooperation and Coordination: An Experiment

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Abstract

We theoretically and experimentally study how information structures of the threshold effort level required to succeed in a joint group task affects cooperation and coordination in the group. We investigate three information structures, complete and symmetric (CS), incomplete and symmetric (IS), and incomplete and asymmetric (IA), as well as a signaling mechanism introduced under IA (IAS) to see what a difference it would make. The theoretical model predicts that, in equilibrium, the performance under IA is the lowest which is intuitive, and a signaling mechanism makes no difference. Furthermore, IS should deliver a higher performance than CS in equilibrium. Our experimental results confirm the prediction that the performance under IA is the lowest among the three information structures, however, CS achieves a significantly higher performance than both IS and IA, and IS just performs as poorly as IA. Furthermore, the signaling mechanism in IAS significantly promotes contribution and public goods provision compared with IA and IS. Between IAS and CS, the contribution and public goods provision is higher in IAS, but the difference is not statistically significant. Our results suggest that, in a cooperation and coordination problem, a simple signaling mechanism can completely overcome the inefficiencies caused by information asymmetry.

Keywords: Information Structure, Asymmetric Information, Threshold Public Goods Game, Cooperation, Coordination, Signaling.

JEL Codes: C71, D71, D82.

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1 Introduction

Stiglitz (2000) emphasizes the role of information in economics. He said "The key question is ... how the economy adapts to new information, creates knowledge, and how that knowledge is disseminated, absorbed, and used throughout the economy." Many economic activities are conducted under incomplete information and probably asymmetric information. Depending on how information is disseminated, different information structures will be constructed. Consider a simple case where a group of salesmen works together to achieve a sales target above which a proportional bonus will be rewarded. The manager chooses among a set of pre-determined values (common knowledge) as the sales target for a certain period. Is it better to reveal this target value to the whole group or only to a single person (e.g., the group leader) or even conceal the information entirely from them (while making the support and the distribution of this information common knowledge)?

Consider another example where several researchers jointly work on a project trying to achieve a certain goal (publish a paper). In order to achieve the goal, at least a certain amount of resources (time, money, etc.) should be devoted to this project, and they all share a common prior about the distribution of the threshold. If they do not manage to achieve the goal (produce a publishable paper), all the resources put into this project would be wasted. However, if the goal is achieved, a shared benefit is provided for the entire group. If they even go beyond the goal (publish in a better journal), a higher benefit is generated. Which information structure would be the best in this case? Revealing the threshold value ex-ante before they start working on the project? Or concealing the information from all the group members? Or informing only one of the group members to create information asymmetry?

In a threshold public goods game (also known as provision point mechanism) with the utilization rebate policy but no refund policy, we investigate the above questions under three different information structures: Complete and Symmetric (CS) where the threshold value is common knowledge, Incomplete and Symmetric (IS) where the threshold value is not known by any player, and Incomplete and Asymmetric (IA) where the threshold value is only known by one player. The utilization rebate policy implies that access contribution of resources above the threshold continues to produce public goods as the examples illustrated above, while a refund policy implies that inadequate contributions (time & efforts) can be recalled later which we do not implement in our study.

A simple theoretical framework is developed in which we focus on symmetric equilibria.[1] The theory predicts that IS should perform better than CS in public goods provision, and IA delivers the worst performance because asymmetric information implies an information rent charged by the privately informed player.[2] Furthermore, we also introduce a signaling mechanism in IA (hereafter IAS, which

[1]The equilibrium we consider is only symmetric *partially* in a sense that players adopt symmetric equilibrium strategies only if they have identical information sets. The detail is presented in section 3.

[2]In a groundbreaking paper, Akerlof (1970) show that it is asymmetric information instead of uncertainty (in a symmetric way) that caused market failure. Another related example is that monopoly and oligopoly are often considered harmful

is basically cheap talk as examined by Crawford and Sobel (1982)) to see what a difference it might make. However, the model predicts that the introduction of a signaling mechanism does not change anything in IA since the private informer would only babble about the threshold value in equilibrium. In addition, MPCR (marginal per capita return) also plays a role in such a setting by changing the set of equilibria at which players should coordinate.[3]

We then experimentally investigate how these three information structures work with different MPCR values and discuss possible explanations. The experiment also features both a between-subject and within-subject design where information structures are implemented between-subject and the MPCR change is implemented within-subject. Therefore, we have four treatments that closely resemble the information structures (CS, IS, and IA) as well as the signaling mechanism introduced in IAS. The experimental results confirm the model's prediction that IA delivers the worst performance among the three information structures, however, the results do not support other predictions. IS does not deliver the best performance among the three of them, and it performs roughly the same as IA. Furthermore, the signaling mechanism in IA plays a significant role in promoting cooperation, coordination, and thus public goods provision, even if the privately informed player sends a false message[4] about her privately observed threshold value. Specifically, IAS induces significantly higher contributions and provides significantly higher public goods compared with either IA or IS. When compared with CS, IAS does induce significantly higher contributions, however, it also provides more public goods while the difference is not statistically significant. Further regression results confirm the non-parametric results that we have obtained.

Our results imply that, although the theory predicts that cheap talk will not help at all in this scenario, the presence of a communication mechanism does improve the economic efficiency of cooperation and coordination under incomplete and asymmetric information, and this might be related to the consistent finding of over-communication in the literature of experimental studies on cheap talk games (see Abeler, Nosenzo, & Raymond, 2019, for a review). Furthermore, IAS can deliver an economic performance that is at least as good as the case with complete information. This further suggests that, in scenarios similar to the game presented in this paper, asymmetric information does not hurt the economic performance as long as we allow the privately informed player to send a message to those uninformed. Thus there is not much need to eliminate information asymmetry by promoting information transparency at a highly increasing marginal cost.

The communication mechanism does the magic by providing a *focal point* for other players to coordinate

to the economy because they raise the price and produce less, and they (can) do this because of two things: 1, they have market power; 2, they do not know consumers' reservation price. In a market with complete information, they would not cause any dead-weight loss, and any Pareto optimal outcome can be obtained by transfers. Generally, the party who has private information over others would demand an information rent which creates inefficiencies and maybe even market failure.

[3]This is mainly the case in IS and IA since (some) players do not know the true threshold level, so they would decide to coordinate at one of the threshold levels and see whether it would constitute an equilibrium. The MPCR value has to satisfy certain conditions for coordinating at a specific threshold level to be in equilibrium.

[4]In treatment IAS, among the messages sent, 42.2% of them are false.

at. In such a game requires both cooperation and coordination, the presence of an obvious focal point (or a rule of thumb) is crucial to successful coordination. Our results clearly show that players in CS contribute their equal share to achieve public goods provision despite a rather constant proportion of free-riders and full-contributors. However, players in IS do not have any clear focal point for them to coordinate at, thus, the performance in IS is the worst. The uninformed players in IA have similar experiences and thus the group performance in IA is roughly the same as that in IS. When the communication mechanism is introduced in IAS, the message sent serves as a clear focal point for other players to coordinate at even if they know that the message could be a lie, and thus greatly increases the ratio of successful public goods provision compared with IS and IA.[5]

We further investigate whether IAS delivers higher contributions (and public goods provisions) at the cost of a higher inequality among players in each group. We examine this by comparing the mean profit across all treatments as well as the mean profit of the non-informed players in IAS. In addition, we also show the comparison of the mean Gini index of individual profits per group per period across the four treatments. The results clear up our doubt on this. First, the mean profit is the highest in treatment IAS, and it is roughly the same between all players and the non-informed players in IAS. Furthermore, the mean Gini index is roughly at the same level across all treatments with a slightly higher mean Gini index in treatment IA, but not IAS. Last but not least, we also control for the potential order effect caused by the order of subjects experiencing different MPCR values.

The remainder of the paper is organized as follows. The next section reviews related literature, section 3 provides a simple framework for analysis. The experimental design and procedure are described in section 4. section 5 presents our results and section 6 concludes.

2 Related Literature

One branch of literature that we are closely related to is the literature on incomplete information in linear public goods game (LPGG hereafter) or threshold public goods game (TPGG). Various forms of incomplete information are examined, and the impact on contribution as well as public goods provision is dependent on the setting.

One form of incomplete information is about asymmetric endowments among players or asymmetric valuation of the public goods, while they do not significantly affect the contribution (as well as provision ratio in TPGG) compared with complete information (M. B. Marks & Croson, 1999; van Dijk & Grodzka, 1992). Another form of incomplete information is mainly about the threshold value, and the effect is mixed. McBride (2006) theoretically show that threshold uncertainty would affect equilibrium

[5]The ratio of successful public goods provision is 62.66% in IAS, 45.00% in IS, and 45.83% in IA. In addition, it is even slightly higher than the provision ratio in CS which is 61.50%.

contributions differently with different threshold distributions and public goods value, while his follow-up experimental study only finds little support (McBride, 2010).

Some studies do show that threshold uncertainty can increase contribution under certain conditions. Suleiman, Budescu, and Rapoport (2001) examine the joint impact of the degree of threshold uncertainty and the threshold mean on people's contribution behavior in a TPGG, and they show that subjects' contribution increases with an increase of the degree of threshold uncertainty when the threshold mean is low, however, it decreases when the threshold mean is high. Compared to a subjective expected utility model, their data supported the cooperative model proposed by Laffont (1975).[6]

However, a larger body of literature has shown that threshold uncertainty is detrimental to contribution and public goods provision. This has been consistently demonstrated in both the threshold public goods game and threshold public bads game[7] (see Kotani, Tanaka, & Managi, 2014; Maas, Goemans, Manning, Kroll, & Brown, 2017, for example). Dannenberg, Löschel, Paolacci, Reif, and Tavoni (2015) also confirms the above result in a TPGG with dynamic contribution, and the situation becomes even worse when the distribution of thresholds is unknown.

Studies also try to show how to ease the problem caused by threshold uncertainty. Maas et al. (2017) show that taxation and punishment are helpful in easing the problem. Guilfoos, Miao, Trandafir, and Uchida (2019) show that communication is effective in enhancing successful coordination merely through cheap talk, while a written message from the last generation has a less significant effect. The cheap talk implemented in their study is free chat in rich text without any restriction between group members, while the form of cheap talk in our study is the typical one-way cheap talk where the sender sends a restricted message to receivers which is popularized by an influential paper by Crawford and Sobel (1982).

Since Crawford and Sobel (1982), extensive studies have investigated many issues in this typical cheap talk game and extended the model in various ways. On one hand, Farrell and Gibbons (1989) and Goltsman and Pavlov (2011) extend the framework by including two receivers in the game with both public and private messages. They suggest that the sender should take the two receivers as a single receiver whose preference lies somewhere between the two receivers', and "private and public communication are equivalent" when the receiver's preferences were perfectly aligned. Battaglini (2002) extends the framework by including two senders and shows that the presence of another sender makes the full revelation of information possible even if the conflict of interest is very large, and Lai, Lim, and Wang (2015) experimentally test this and show that more information can be transmitted with two senders in the game.

Many experimental studies have been conducted on cheap talk games and have shown consistently that

[6] The model is based on Kant's principle, and Laffont (1975) proposed that "a typical agent assumes (according to Kant's moral) that the other agents will act as he does, and he maximizes his utility function under this new constraint.

[7] Threshold public bads game are also commonly known as common pool resource game (CPR) with threshold uncertainty.

over-communication is prevalent in various settings (see Abeler et al., 2019; Blume, Lai, & Lim, 2020, for reviews). Furthermore, studies also report that not only do the senders over-communicate and thus transmit more information on the true states of the world, but the receivers are also more credulous towards the message received and thus they rely on them to make their decisions (see Battaglini & Makarov, 2014; Cai & Wang, 2006, for example). In addition, these observations are most consistent with learning and level-k reasoning (Blume et al., 2020; Minozzi & Woon, 2016; Wang, Spezio, & Camerer, 2010), and Abeler et al. (2019) suggests that "a preference for being seen as honest and a preference for being honest" is the main driven force of the observed over-communication.

Among the large body of literature on experimental studies, T. R. Palfrey and Rosenthal (1991) and T. Palfrey, Rosenthal, and Roy (2017) are the closest to our study in which they examine the effect of cheap talk on contribution and provision in a TPGG where players had homogeneous valuations but heterogeneous costs of contribution. T. R. Palfrey and Rosenthal (1991) utilize the solution concept of sequential equilibrium on the issue, while T. Palfrey et al. (2017) take the approach of mechanism design to address the issue, and they found that only the richest and unrestricted text chat approach yielded a significantly higher provision. Our study is different from theirs in several ways: (i) The contribution is binary in their setting, and it is continuous in our game, (ii) The asymmetric information is the cost of contribution in their study, while it is threshold uncertainty in our game, and (iii) their main focus is how different communication technique affects coordination, while ours is on how different information structure, as well as communication in IA, would affect coordination and cooperation.

3 The Game

There are N players in this threshold public goods game. Each player $i \in \{1, \cdots, N\}$ has an endowment E, and contributes $a_i \in [0, E]$ to a public account to achieve public goods provision. The provision of public goods is dependent on the state of the world $\theta \in \Theta \equiv \{\theta_i | 0 < \theta_1 < \cdots < \theta_K \leqslant E \times N\}$, and all players share a common prior over the states that is characterized by $\mathbb{P} \equiv \{p_i \,|\, p_i > 0, \sum_{i=1}^{K} p_i = 1\}$ correspondingly.

The public goods will be provided only if the total contribution $\sum_i a_i \geqslant \theta$, and it will benefit all players equally with $\rho \in \left(\frac{1}{N}, 1\right)$ as the marginal per capita return (MPCR) once provided.[8] The utility function for each player is specified as follows:

$$U_i = E - a_i + I\left(\sum_i a_i \geqslant \theta\right) \rho \sum_i a_i \tag{1}$$

[8]Since there are N players, $\rho > \frac{1}{N}$ implies that individual contributions produce a larger benefit for the entire public as long as public goods are provided, and $\rho < 1$ implies that individual contributions are not optimal for each individual. This creates a tension between individual and collective interests such that the question is worth investigating.

where $I(\cdot)$ is an indicator function that takes the value of 1 if $\sum_i a_i \geqslant \theta$ and 0 otherwise.[9]

Equation (1) implies that we adopt a utilization rebate policy[10] but without any refund policy, and we consider this to be more relevant to certain real-life scenarios discussed in the Introduction. Normally, a rebate policy is used to take care of excess contributions over the threshold so that they are not wasted, while a refund policy takes care of inadequate contributions below the threshold.

It is straightforward to see that collectively free-riding, $a_i = 0$ for all $i \in \{1, \cdots, N\}$, is a Nash equilibrium (NE) irrespective of θ and how the information about θ is disseminated. No one has any incentive to deviate from free-riding as it would only make him/her worse off. In the following part of the paper, we mainly focus on non-free-riding equilibria under certain assumptions. In addition, we only focus on pure strategy equilibrium in this coordination and cooperation problem as mixed strategies will only lead to inefficiency and more wasted contributions. Throughout the section, we assume that players are risk neutral and expected utility maximizers

3.1 Complete & Symmetric Information Structure

Let us first consider the case of complete and symmetric information structure (CS) where θ is common knowledge, and the solution concept we use is simply Nash equilibrium (NE hereafter). Each player knows the true state of world θ and knows that it is in equilibrium to coordinate at θ with $\sum_i a_i = \theta$. As a result, there is an infinite number of equilibria for each θ which makes it extremely difficult (almost impossible) to perform equilibrium analyses of the game.

One simplification we make in the game is by focusing on symmetric play among the players.[11] Since we are investigating different information structures of the game where players might have different information regarding the structure of the game (state of the world θ), we would like to impose a restriction on symmetric play among the players stated in Assumption 1 as follows.

Assumption 1 (Symmetric Strategy): *Players use symmetric contribution strategies if they share the same information on $\theta \in \Theta$.*

This assumption helps us ease the analyses of the game in two important ways while enabling us to obtain key insights on the issue at the same time. First, it allows us to focus on the issue at which specific θ

[9]In general, an indicator function $I(\cdot)$ equals 1 when the condition in its parenthesis is satisfied and 0 otherwise.

[10]We choose the utilization rebate policy mainly because it is quite intuitive and easy to understand by experimental subjects. Isaac, Schmidtz, and Walker (1989) first examine the utilization rebate policy which was further studied by M. Marks and Croson (1998). M. Marks and Croson (1998) examined three rebate policies, proportional rebate, utilization rebate, and no rebate in TPGG, and their results showed that, although the provision ratio of public goods did not differ among different rebate policies, contributions are significantly higher under utilization rebate policy than the other two while the variance of contributions was also the highest under utilization rebate policy.

[11]One rationale for symmetric play in threshold public goods game is in the spirit of focal point theory. Schelling (1960) proposes the idea of focal point and states that "people can often concert their intentions or expectations with others if each knows that the other is trying to do the same". Since equity is usually a common concern for most people as suggested by Fehr and Schmidt (1999) and Bolton and Ockenfels (2000), the symmetric play becomes a natural focal point for players to coordinate at.

players can successfully coordinate and thus constitute an equilibrium, rather than the issue of equilibrium selection at a particular θ among many different combinations of contributions that can lead to successful coordination. Second, it simplifies our analyses and comparisons between different information structures by a lot. Though it does not encompass all the potential equilibria out there, it still provides important insights into the impacts of information structure on coordination and cooperation. With Assumption 1, it is straightforward to have all players' equilibrium play under a complete and symmetric information structure which is specified in Proposition 1. All proofs of propositions and lemma are relegated in Appendix B.

Proposition 1: *Under complete and symmetric information, for each $\theta \in \Theta$, there is a unique pure strategy NE where each player contributes $\dfrac{\theta}{N}$, $\forall\, \theta \in \Theta$.*

3.2 Incomplete & Symmetric Information Structure

In this part, we consider the case of incomplete and symmetric (IS) information structure where each player knows nothing about θ and the solution concept we use is still NE.[12] Suppose that all players decide to coordinate at $\theta_k \in \Theta$ and each contributes $\dfrac{\theta_k}{N}$ according to Assumption 1. For any state $\theta \leqslant \theta_k$, public goods will be provided. However, if the state $\theta > \theta_k$, public goods will not be provided and all the contributions are wasted since there is no refund rule in the game. Thus, each player's utility is given by the following equation:

$$\mathbb{E}(U_i) = E - \frac{\theta_k}{N} + \rho\theta_k \sum_{i=1}^{k} p_i \tag{2}$$

Coordinating at θ_k can constitute a NE if each player has no incentive to deviate his contribution upwardly or downwardly. Let $a_{i,g} = \max\left(0,\, \theta_g - \dfrac{(N-1)\theta_k}{N}\right)$ and Θ^*_{IS} denote the set of θ_k at which coordination constitutes an equilibrium, as well as $\theta_0 = p_0 = 0$ to cover the scenario where one player deviates to free-riding and nothing is provided. Now we give the conditions that characterize Θ^*_{IS} in the following proposition.

Proposition 2: $\forall\, \theta_k \in \Theta$, $\theta_k \in \Theta^*_{IS}$ *if and only if the following conditions are satisfied:*

$$\theta_k(1 - \rho\sum_{i=1}^{k} p_i) \leqslant \theta_f(1 - \rho\sum_{i=1}^{f} p_i), \qquad \forall\, f \in \{k+1, \cdots, K\} \tag{3}$$

$$\rho\theta_k \sum_{i=0}^{k} p_k - \frac{\theta_k}{N} \geqslant \rho\left(\frac{(N-1)\theta_k}{N} + a_{i,g}\right)\sum_{i=0}^{g} p_i - a_{i,g}, \qquad \forall\, g \in \{0, \cdots, k-1\} \tag{4}$$

[12] Someone might argue that we should use Bayesian Nash equilibrium under incomplete information. However, the information structure is symmetric and each play does not have different types. Of course, we can define each player's type as the θ s/he decides to coordinate at, however, one would instantly know all other players' types given Assumption 1. As a result, NE should still be applied here.

3.3 Incomplete & Asymmetric Information Structure

We now consider the case of incomplete and asymmetric (IA) information structure where only one player privately observes θ and the solution concept we use is Bayesian Nash equilibrium (BNE hereafter).[13] Suppose one S player (she) privately observes the true state of world (denoted as) θ_T while others do not who are R players (they).

Let Θ^*_{IA} denote the set of θ at which coordination is in equilibrium for all R players, thus each R player would contribute $a_r = \theta_k/N$ according to Assumption 1. We then characterize Θ^*_{IA} by characterizing the best responses of the S player in Lemma 1 first and then specify the conditions under which one R player has no incentive to deviate fixing all other players' strategies.

Lemma 1: $\forall\, \theta_k \in \Theta^*_{IA}$*, each R player would contribute* $\dfrac{\theta_k}{N}$*, and the S player's best response is to contribute* $I(a_s(\theta_T, \theta_k))a_s(\theta_T, \theta_k)$*.*

Where $a_s(\theta_T, \theta_k) \equiv \max\left(0,\, \theta_T - \dfrac{(N-1)\theta_k}{N}\right)$ and $I(a_s(\theta_T, \theta_k)) \equiv I(a_s(\theta_T, \theta_k)) \leqslant \min(E,\, \rho\theta_T)$ is an indicator function that takes the value of 1 if the condition in the parenthesis is satisfied and 0 otherwise. The intuition behind Lemma 1 is that the S player would only contribute the necessary margin to achieve public goods provision if it is possible and beneficial for her to do so. $a_s(\theta_T, \theta_k)$ is the required margin to achieve public goods provision, and $I(a_s(\theta_T, \theta_k))$ selects all the $\theta_T \in \Theta$ at which it is possible and beneficial for the S player to contribute.

Given the R player's contribution strategy in equilibrium, the S player's best response is a contingent plan on the true state of world θ_T that she observes. This also applies to the case when a signaling mechanism is introduced that only changes the R player's belief on the distribution of θ and thus alters the set of θ at which coordination is in equilibrium.

Next we specify the conditions that one R player has no incentive to deviate from$a_r = \theta_k/N$, $\forall \theta_k \in \Theta^*_{IA}$. Given the S player's best response described in Lemma 1, each R player's expected utility function is as follows:

$$\mathbb{E}(U_R(\theta_k)) = E - \frac{\theta_k}{N} + \rho \sum_{i=1}^{K} p_i I(a_s(\theta_i, \theta_k)) \left(a_s(\theta_i, \theta_k) + \frac{(N-1)\theta_k}{N} \right) \tag{5}$$

Consider the case where one R player has incentives to deviate upwardly. Define $\Theta_f = \{\theta_f \,|\, \theta_f \in \Theta,\, I(\theta_f) = 0 \;\&\; a_{r,f} \leqslant E\}$ which is the set of θ_f where public goods will be provided if one R player would deviate his contribution upwardly, where $a_{r,f} = \theta_f - \dfrac{(N-2)\theta_k}{N}$ is the required contribution from him to achieve public goods provision at θ_f. Thus, his expected payoff after deviation is described as

[13] One can consider that the state of world θ is the S player's type, and the R players only have one type.

follows:

$$\mathbb{E}(U_R(\theta_f)) = E - a_{r,f} + \rho \sum_{i=1}^{f} p_i \left(\theta_f + I(a_s(\theta_i, \theta_k))a_s(\theta_i, \theta_k)\right) \tag{6}$$

Now let's consider the case where one R player deviates his contribution downwardly. Define $\Theta_g = \{\theta_g \,|\, \theta_g \in \Theta \cup 0,\ \theta_g - \dfrac{(N-1)\theta_k}{N} < 0\}$, and $a_{r,g} = \max\left(0,\ \theta_g - \dfrac{(N-2)\theta_k}{N}\right)$ is the required contribution to achieve public goods provision. Thus, his expected utility is described as follows:

$$\mathbb{E}(U_R(\theta_g)) = E - a_{r,g} + \rho\left(a_{r,g} + \frac{(N-2)\theta_k}{N}\right)\sum_{i=0}^{g} p_i \tag{7}$$

We finally summarize the conditions that each R player has no incentive to deviate from coordinating at θ_k in the following proposition.

Proposition 3: $\forall\, \theta_k \in \Theta,\ \theta_k \in \Theta^*_{IA}$ *if and only if the following conditions are satisfied:*

$$\mathbb{E}(U_R(\theta_k)) \geqslant \mathbb{E}(U_R(\theta_f)), \qquad \forall\, \theta_f \in \Theta_f \tag{8}$$

$$\mathbb{E}(U_R(\theta_k)) \geqslant \mathbb{E}(U_R(\theta_g)), \qquad \forall\, \theta_g \in \Theta_g \tag{9}$$

3.4 IA Information Structure with Signaling

In this section, we consider the case of incomplete and asymmetric information structure with signaling (IAS hereafter) where the S player can send a public message $m \in M \subseteq \Theta$ to all R players according to a specific messaging strategy $\mu(m|\theta)$, and the R players will form their posteriors $\alpha(\theta|m_l)$ according to Bayes' rule. Then all players decide their contribution decisions when R players have received m. Similarly, we define Θ^*_{IAS} as the set of θ_k at which coordination constitutes an equilibrium.[14]

Babbling equilibrium always exists, and the case deteriorates into the incomplete and asymmetric information structure without signaling, thus $\Theta^*_{IAS} = \Theta^*_{IA}$. Truth-telling ($m = \theta$) is not an equilibrium as the S player always wants to send $m > \theta$, and neither does any fully separating messaging strategy. For any partial pooling messaging strategies, as long as the S player's induced expected utilities from two different messages are different, the S player would switch her messaging strategy from one to the other. As a result, S player's induced expected utilities are the same for all $m \in M$, thus, S can babble across all messages.[15] Therefore, we have the following proposition.

Proposition 4: *In equilibrium, the S player's messaging strategy is always babbling, i.e.,* $\Theta^*_{IAS} = \Theta^*_{IA}$.

[14] Θ^*_{IAS} could be a set of $Theta^*_m$ which is the set of θ at which coordination is an equilibrium when the S player sends a message m. This corresponds to a partition equilibrium. In addition, a full characterization of the equilibrium is $\{\mu(m|\theta), (a_s(\theta_T, \theta_k), a_r = \theta_k(N-1)/N, \forall\, \theta_k \in \Theta^*_m \subseteq \Theta^*_{IAS})\}$ where Θ^*_m is the set of θ at which coordination is in equilibrium when R players receive message m. However, this is not necessary as we are going to show that there is only babbling equilibrium in this game. Please see Appendix B for more details.

[15] This is mainly due to the fact that S prefers the expected contributions from all R players as high as possible irrespective of the state of world θ.

This stands in contrast to traditional cheap talk games where a partition equilibrium exists as long as the S player's and R players' preferences are not too misaligned, as shown by Crawford and Sobel (1982) for example (CS hereafter). The key difference is in the utility function between our setup and CS's. They assume the S's utility function is strictly supermodular with respect to R's action and S's type (state of world in our setup) which implies that R's taken action that is optimal for S should be increasing in the state of world, and the optimal state of world should also be increasing in R's action. In our setup, however, S's utility function is neither supermodular nor submodular. Specifically, on one hand, irrespective of the state of world θ, S always prefers the highest contribution from all the R players. On the other hand, for any level of contribution from R players, S prefers θ to be low enough such that she does not have to contribute.

The specific equilibrium set $\Theta^*_{IAS} = \Theta^*_{IA}$ at which the R players would coordinate is dependent on the parametrization of the game. Next, we show a simple parametric example as well as the corresponding equilibrium set of θ under different information structures.

3.5 A Parametric Example

Let us consider $N = 3$, $E = 20$, $\Theta = \{\theta_1 = 24, \theta_2 = 36, \theta_3 = 60\}$, and $\mathbb{P} \equiv \{p_1 = p_2 = p_3 = 1/3\}$. The threshold values are chosen such that, in IAS, the privately informed S player could potentially take advantage of the R players to the maximum degree (while she cannot in equilibrium). For example, if the R players decides to coordinate at $\theta_2 = 36$, the S player can completely free-ride on them with successful public goods provision when the state is $\theta_1 = 24$.

According to Proposition 1, 2, 3, and 4, the equilibrium set of θ under each information structure is described in the following table:[16]

Table 1: Equilibrium Strategy w.r.t. Information Structure and MPCR

<table>
<tr><th></th><th>CS</th><th>IA/IAS</th><th>IS</th></tr>
<tr><td>$\rho \in (0.33, 0.43)$</td><td rowspan="4">Coordinating at θ</td><td>None</td><td>None</td></tr>
<tr><td>$\rho \in [0.43, 0.56)$</td><td>Coordinating at $\theta = 60$</td><td>None</td></tr>
<tr><td>$\rho \in [0.56, 0.6)$</td><td>Coordinating at $\theta = 60$
or $\theta = 24$</td><td>None</td></tr>
<tr><td>$\rho \in [0.6, 1)$</td><td>Coordinating at $\theta = 60$
or $\theta = 36$
or $\theta = 24$</td><td>Coordinating at $\theta = 60$</td></tr>
</table>

`None` implies that there is no other equilibrium than collectively free-riding.

[16] For detailed derivation of the results, please refer to Appendix B.

4 Experimental Design & Procedure

The stage game that is played in our experiment closely resembles the framework presented in Section 3, and the parameters we use are the same as the example presented in Section 3.5, specifically, we have $N = 3$, $E = 20$, $\Theta = \{24, 36, 60\}$, and $\mathbb{P} \equiv \{1/3, 1/3, 1/3\}$.

4.1 Design and Treatments

We have four experimental treatments that closely resemble the four scenarios studied in Section 3, specifically, we have: (i) CS treatment where θ is common knowledge; (ii) IS treatment where θ is unknown to all players; (iii) IA treatment where θ is only privately observed by one S player; (iv) IAS treatment where the S player needs to send a message $m \in \Theta$ indicating the value of θ to other R players.

As shown in Table 1, the MPCR value ρ affects the equilibria under certain information structures. However, when $\rho \in [0.6, 1)$, the equilibrium strategy in each treatment is fixed. In particular, in CS, coordinating at the observed $\theta \in \Theta$ is the unique non-free-riding equilibrium; in IS, coordinating at $\theta_3 = 60$ is the unique non-free-riding equilibrium; in contrast, in IA and IAS, coordinating at any $\theta \in \Theta$ can be an equilibrium. The difficulty of successful coordination in IA and IAS is much higher than that in CS and IS simply due to the differences in the number of equilibria. Therefore, we should anticipate a lower provision ratio of public goods in IA and IAS, and thus lower public goods provision.

Though CS and IS both have a unique non-free-riding equilibrium strategy, the θ at which players coordinate in equilibrium in IS is higher than or equal to that in CS. This implies that, (i) conditional on successful coordination, IS treatment generates higher public goods provision, higher profit, and thus higher welfare, however, (ii) successful coordination in IS requires higher contributions which are more demanding. As a result, we should anticipate that, conditional on successful public goods provision, higher public goods are provided in IS.

To ease the high contribution demanded from each player in equilibrium in IS, we make the equilibrium strategy in IS less demanding by increasing ρ such that it is still beneficial for one player to contribute $\theta_3/3$ as long as there's another player will do the same. This imposes an additional restriction as follows: $\dfrac{2}{3} \times 40\rho \geqslant 20 \Longrightarrow \rho \geqslant 0.75$. Therefore, we take two different values of ρ in each treatment to have both cases studied: (i) one is $\rho = 0.6$ where coordinating at θ_3 in equilibrium in IS requires each player to contribute θ_3; (ii) and another is $\rho = 0.8$ where coordinating at θ_3 in IS is beneficial for one player if there is another player would do the same.

To sum up, our experiment features both between-subject and within-subject designs where the information structure is between-subject and the change in ρ is within-subject. The two values chosen for ρ are 0.6 and 0.8, and subjects will play the game with $\rho = 0.6$ in the first part of the experiment and $\rho = 0.8$ in the second one.

In order to control for any potential order effect, we also reverse the order of experiencing these two ρ values in different sessions. In this way, we can test whether there will be any order effect or not, and more importantly, how robust our results are against the order effect if there is any. The experimental design is summarized in Table 2.

Table 2: Experimental Design

Treatment	CS		IS		IA		IAS	
Session	CS6	IS6	IA6	IAS6	CS8	IS8	IA8	IAS8
Part 1	$\rho = 0.6$				$\rho = 0.8$			
Part 2	$\rho = 0.8$				$\rho = 0.6$			
Part 3	Lottery Task To Control Risk Attitude							

In each part, the corresponding stage game described in Section 3 will be played for 20 periods. A group of three is randomly formed among the subjects and the group formation is fixed throughout the game. There is no feedback provided for each player after each period, so that any potential learning effect is minimized and, to the largest extent, the game becomes a repetition of the one-shot stage game. At the very end of the experiment, each subject gets a summary of the outcomes of all previous plays in each period including the payment, the profit, and the provision status of public goods. In treatments CS, IS, and IA, there is no communication mechanism, and each subject makes the decision independently. In treatment IAS, the S player has to send a message $m \in \{24, 36, 60\}$ to the R players indicating the threshold value θ she has privately observed.

After the two parts of the threshold public goods game with different ρ values, subjects also go through a multiple price list lottery task as a control of their risk preference. In the follow-up questionnaire, on top of the commonly collected demographics, we also collect data on the measure of subjects' *Agreeableness*, which is a sub-domain of the Big-Five model of personality, based on Costa Jr and McCrae (1992).[17] We choose the sub-domain *Agreeableness* from the Big-Five model because it contains the facets that we consider to be the most relevant to cooperation and coordination, which are trust, morality, altruism, cooperation, modesty, and sympathy.

[17] It is not from Costa Jr and McCrae (1992)'s original version since it is copyrighted. Goldberg together with his colleagues initiated the International Personality Item Pool, and we use Goldberg's IPIP version which is a revised version of Costa Jr and McCrae (1992)'s.

4.2 Theoretical Predictions

As **??** shows that, except for the free-riding equilibrium which is universal across treatments, information structure and the ρ value jointly affects the equilibrium at which players are going to coordinate.

At equilibrium, players in CS would contribute exactly one-third of the realized threshold level, $\theta/3$, no matter what value ρ takes. Players in IS and IA will behave differently according to ρ. Based on the theoretical predictions summarized in **??**, we have our first theoretical prediction.

Prediction 1: *In equilibrium (except the free-riding one), players in CS contribute one-third of the realized threshold θ, players in IS will contribute 20, and players in IA and IAS will contribute either 0 or 8 or 12 or 20.*

From a theoretical point of view, IS is actually better than IA for two reasons. First, the IS treatment's number of equilibria is less than that of the IA treatment, which is an advantage for coordination problems. Second, one player in the IA treatment will claim an information rent by free-riding when the threshold level is low, however, in the IS treatment, no one has any information advantage so no one can be taken advantage of. Therefore, we would expect a higher contribution level as well as a higher level of public goods provided in IS than in IA. Similarly, IS should perform better than CS.

Prediction 2: *In equilibrium (except the free-riding one), the ranking of performance under the three information structures is: IS > CS > IA.*

Prediction 2 is also consistent with the literature. Previous studies also adopt a random threshold mechanism (even drawn from unknown distributions) hypothesizing that it might help increase contributions by withholding threshold information so that players need to contribute more in order to achieve public goods provision (Rondeau, D. Schulze, & Poe, 1999; Spencer, Swallow, Shogren, & List, 2009). Withhold information partially in treatment IA and IAS does not have this effect since information asymmetry creates some discrepancies and mistrusts between the S player and the R players, and they know that she would take advantage of them whenever she can.

Prediction 3: *In equilibrium (except the free-riding one), the provision of public goods in IAS should be similar to that in IA, and thus significantly lower than that in CS and IS.*

4.3 Experimental Procedure

The experiment was conducted at the CATI lab, School of Social Science, Nanyang Technological University using ztree (Fischbacher, 2007). Participants were recruited from a pool of undergraduate volunteer subjects via email. Upon arrival, the experimenter read the instructions aloud while participants were reading their own copies at the same time. Each part of our experimental instructions is read separately from the next one, so participants can focus on the current task. Sessions lasted around 60 minutes and each participant earned on average S$15 including a show-up fee of S$2. In total, we have 186 undergraduate students who participated in our experiment with 85 male students and 56 female students. The detailed demographics across all the treatments are shown in Table 3.

Table 3: Demographics Across All The Treatments

Treatment	No. of Subjects	Male Ratio	Age	Nationality	% Experiment-Exp	% Theory-Exp
CS6	24	54.2%	22.9	70.8%	91.7%	37.5%
CS8	21	76.2%	23.0	52.4%	100%	42.9%
IS6	24	62.5%	22.6	54.2%	100%	25.0%
IS8	24	54.2%	22.5	62.5%	83.3%	29.2%
IA6	24	54.2%	23.0	45.8%	66.7%	37.5%
IA8	21	52.4%	22.1	28.6%	61.9%	28.6%
IAS6	24	50.0%	23.0	87.5%	95.8%	37.5%
IAS8	24	66.7%	22.4	70.8%	87.5%	50.0%
Total	186	58.6%	22.7	59.7%	86.0%	36.0%

Nationality represents the percentage of Singaporeans. % Experiment-Exp is the percentage of subjects that have experiences in other experiments before. % Theory-Exp is the percentage of subjects that have learned some knowledge on game theory before.

5 Results

Since the randomness of threshold level is implemented period by period through a computer random device, it could be the case that the realized distribution of threshold is significantly different in one or several treatments from others, and the observed results might be due to this difference rather than the difference in information structures. Therefore, we first perform a K-W test of the distribution of realized threshold values with respect to $\rho = 0.6$, $\rho = 0.8$, and the pooled data, and the corresponding p-values are 0.511, 0.295, 0.173. Therefore, we are confident to say that the observed treatment differences in the following sections are mainly driven by the difference in information structures as well as the presence of the communication mechanism.

5.1 Equilibrium Play Across Treatments

We first look at the contribution behavior across different treatments and see to what extent it conforms to our theoretical predictions, especially Prediction 1. Figure 1 shows the distribution of contributions under different threshold values across different treatments, where each column represents a specific treatment, and each row corresponds to a specific threshold level. A dashed vertical line indicates the predicted equilibrium play in each treatment. Since each session has a within-subject variation of MPCR value, this is the contribution distribution pooled over MPCR = 0.6 and MPCR = 0.8 for each treatment.[18]

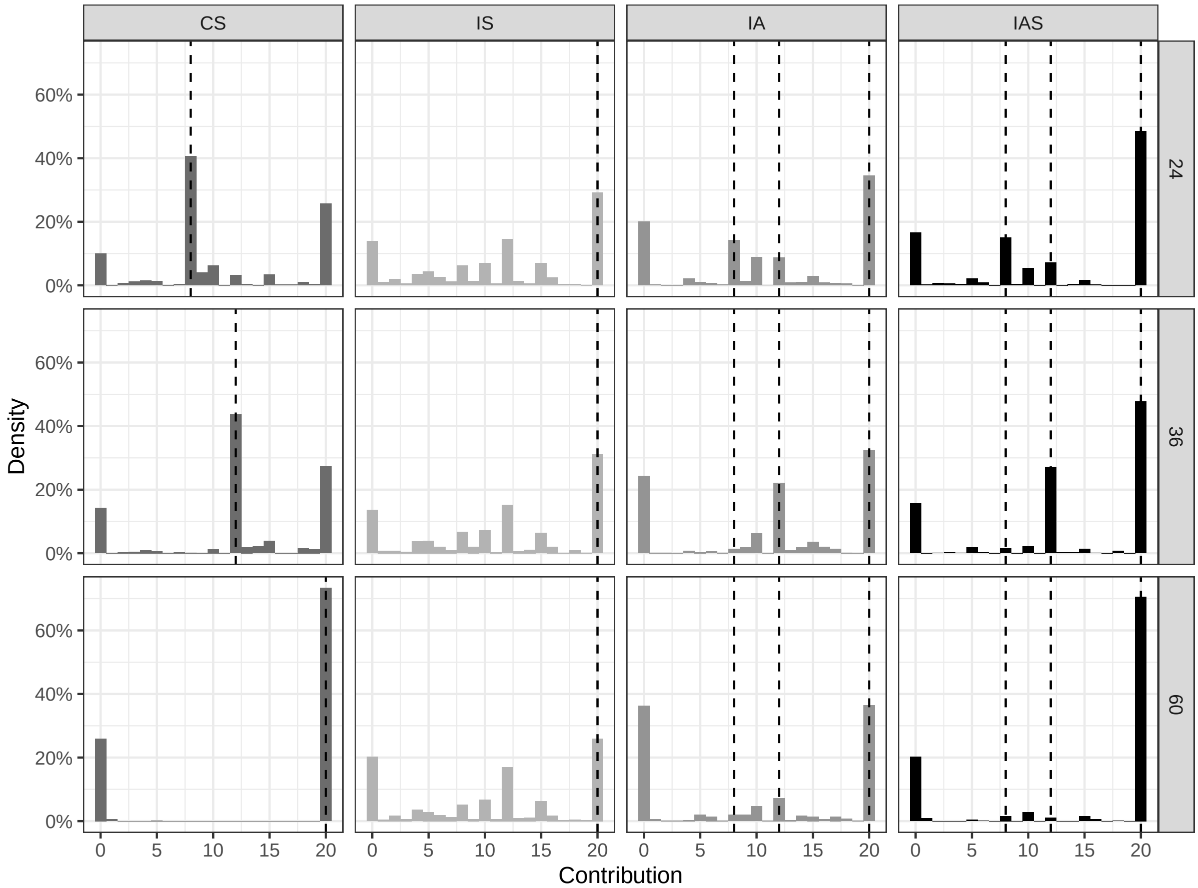


Figure 1: Contribution Distribution Across Treatments & Threshold Levels

From Figure 1 we can see that, in CS, the contribution level has a high spike where it equals one-third of the threshold level which is also the predicted equilibrium strategy. For example, when the threshold level is 24, there is a spike at contribution level 8 consists of more than 40% of the observations. Aside from this, there are also two spikes at contribution levels 0 and 20, which we refer to as free-riding and unconditional full contribution. These two types of play seem to constitute a rather stable portion of the population. Next look at the case when the threshold level is 36, despite the two spikes at contribution levels 0 and 20, there is an even higher spike at 12 which is also one-third of the threshold. Finally, when the threshold level is 60, the equilibrium play, one-third of the threshold level, coincides with the unconditional full contribution strategy, so we observe an extremely high spike at contribution level 20 that constitutes over 70% of the observations. And there's almost no other contribution except free-riding and full contribution. Thus, Prediction 1 is well supported under CS information structure.

Moving to IS, the contribution behavior deviates the most from the equilibrium prediction. Prediction 1 suggests that there is only one equilibrium play — contributing 20 — except the free-riding equilibrium under both $\rho - 0.6$ and $\rho - 0.6$. However, despite a very similar proportion of full-contributors with

[18]Separating the data into MPCR = 0.6 and MPCR = 0.8 has litter impact on the distribution of contributions. Please see Figure 5 and 6 in Appendix A for the distribution regarding each MPCR value.

that in CS, the contributions are noisy and scattered the most among the three information structures. Therefore, Prediction 1 is not supported in IS information structure.

in IA, Prediction 1 suggests that the R players will coordinate at any $\theta \in \{24, 36, 60\}60$ and thus contribute 8 or 12 or 20 respectively. The S player contributes 0 or 8 or 12 or 20 depending on the true threshold θ_T and R's action in equilibrium, so we should expect, under any threshold level, spikes of contribution are at 0, 12, and 20 which is only partially supported. Except free-riding and full contributions, there is a spike at 8 when $\theta = 24$, at 12 when $\theta = 36$, and no evident spike when $\theta = 60$. This difference in the contribution pattern w.r.t θ in IA is mainly driven by different contributions made by the S player who privately observes θ, and when $\theta = 60$, the S player shifts her contribution to free-riding.

However, IAS produces a quite different distribution of contributions from IA although Prediction 3 suggests that they should produce similar results. The first observation is that the proportion of free-riding and non-equilibrium plays is less than that in IA. Furthermore, the proportion of full contribution is evidently higher than that in IA. In addition, The contribution distribution roughly mimics the pattern observed in CS with a shift from the equal split contribution strategy to full contributions.[19]

Nonetheless, the highest spikes of contribution in IAS are 8, 12, or 20 except for those who free-rides, and this observation also (partially) holds in IA and IS although the contribution decisions are noisier. This suggests that players tend to adopt symmetric contribution strategies to coordinate at a specific threshold level θ no matter whether this θ is directly observed (CS), from a message that might be a lie (IAS), or according to one's belief (IS and IA), and this symmetric contribution strategy is much easier to be adopted when a focal point is provided either by direct observations or indirect messages from the S player. In addition, the noisier contributions observed in IS and IA are mainly due to the fact that there is not a common focal point to coordinate at.[20]

Result 1: *Despite a rather constant portion of free-riders and full contributors, a great majority of players adopt the symmetric contribution strategy to coordinate at a specific threshold level especially when there is a focal point to guide and facilitate their coordination.*

5.2 Impact of Information Structure

In this section, we first present the results in Figure 2 comparing different variables across treatments including mean contributions, mean provision ratio of public goods, the amount of public goods provided, the mean wasted contributions due to mis-coordination (since we do not have a refund policy), mean welfare (provided public goods minus mean wasted contribution), and mean public goods provided

[19] This is mainly the result of the S player's messaging strategy which generally over-reports the threshold instead of babbling, and this will be discussed in detail in section subsection 5.3.

[20] Although the theory predicts that there is only one equilibrium in IS, it requires much higher cognitive power to figure it out compared with the cases with a common focal point to coordinate at.

conditional on successful provision. In addition, we also test the significance of any differences between treatments using the clustered Wilcoxon Rank-Sum test (denoted as C-WRS test hereafter).[21] Two-sided C-WRS tests are applied unless it is specified otherwise.

Figure 2(a) shows the mean contributions across these four treatments.[22] The mean contributions in IA (11.12) is the lowest which confirms Prediction 2, while the mean contributions in IS (11.32) is roughly the same as that in IA, and there is no significant difference between them ($p = 0.931$) which violates Prediction 2.

The mean contribution in CS (12.62) which is higher than that in IS or IA, however, this difference is not statistically significant ($p = 0.261$ and $p = 0.217$ respectively). The highest mean contribution is observed in IAS (13.93), and the difference in contribution between IAS and IS or that between IAS and IA is statistically significant ($p = 0.022$ and $p = 0.015$ respectively), while the difference between IAS and CS is only marginally significant ($p = 0.076$). Therefore, the highest mean contribution is elicited in the presence of the signaling mechanism which violates the Prediction 3.

However, Figure 2(b) shows that the mean provision ratio between CS and IAS is roughly the same (62.7% vs 61.5%, $p = 0.900$),[23] so the public goods provided in IAS should be higher than that in CS given the contribution in IAS is marginally significantly higher. Figure 2(c) confirms this conjecture and shows that the mean public goods provided in IAS (29.91) is higher than that in CS (25.95), however, this difference is not statistically significant ($p = 0.293$).[24]

On the other hand, the mean provision ratios in IS and IA are the lowest (45.0% and 45.8% respectively), and the difference in provision ratio between IS and IAS or between IA and IAS is statistically significant ($p = 0.066$ and $p = 0.065$ respectively). Consequently, the mean public goods provided in IS and IA (19.56 and 19.30 respectively) are both significantly lower than that in IAS ($p = 0.039$ and $p = 0.032$ respectively), but not statistically lower than that in CS ($p = 0.249$ and $p = 0.239$ respectively).

Another concern is the wasted contributions (since we do not have a refund policy) which is a measure of the social loss in our experiment. Since IAS induces significantly higher contributions than other treatments, it might also produce higher wasted contributions due to mis-coordination which casts doubts on the effectiveness of IAS in raising contributions.

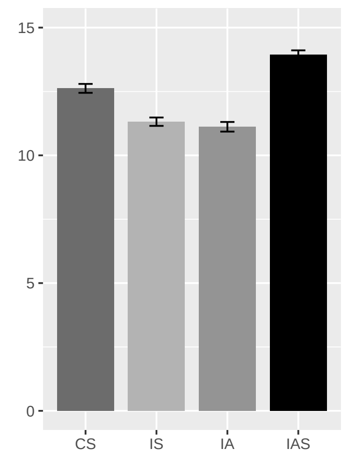
Figure 2(d) and Figure 2(e) together address this concern. Figure 2(d) shows that the mean wasted contributions in IAS and CS are almost the same (11.88 and 11.91 respectively). This implies that IAS

[21]Similar to the case in Chapter 1, we have repeated observations at the group level which are not independent of each other, therefore, each group is taken as a cluster in our data analyses. And we use the D-S method proposed by Datta and Satten (2005).

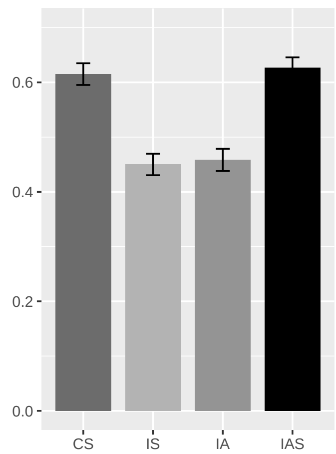
[22]For a more detailed descriptives on contributions with respect to each value of ρ and θ as well as the sequence of implementing different values of ρ, please see Table 6 in Appendix A.

[23]For a more detailed description of provision ratios with respect to each value of ρ and θ as well as the sequence of implementing different values of ρ, please see Table 7 in Appendix A.

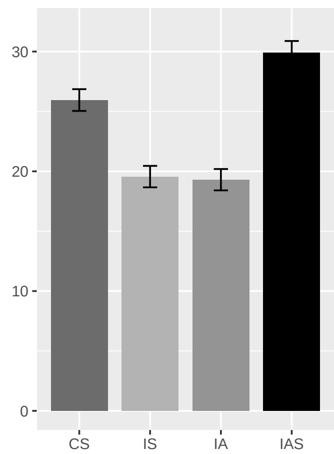
[24]This is largely due to the number of zero values in both treatments when public goods are not provided.



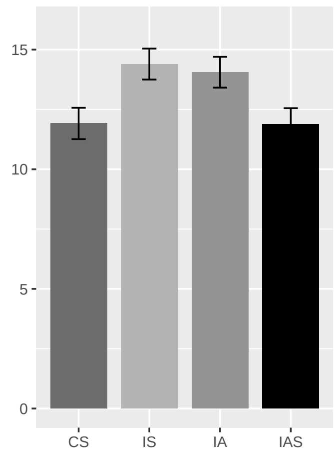
(a) Contribution



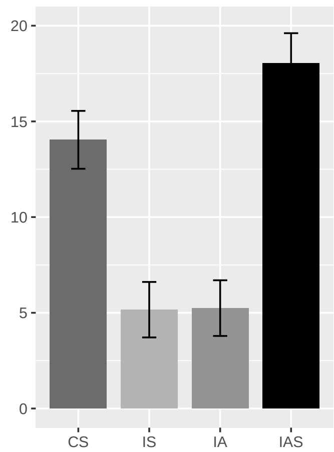
(b) Provision Ratio



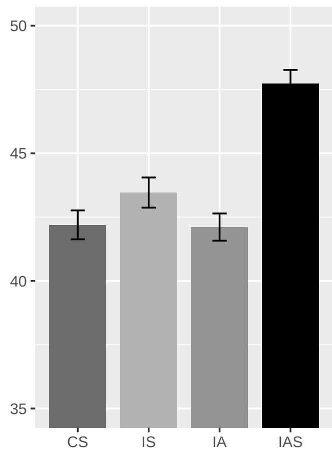
(c) Public Goods Provided



(d) Wasted Contribution



(e) Welfare



(f) Conditional Provision

Figure 2: Contribution, Provision, Efficiency, and Welfare Across Treatments

treatment is generally better than CS treatment in providing more public goods without wasting more resources. These results are combined in Figure 2(e) which shows the mean welfare by taking the benefit of public goods provision and the cost of wasted contribution together. It shows that the resulted welfare in IAS (18.03) is evidently higher than that in IS or IA (5.16 and 5.25 respectively) and the difference is marginally statistically significant ($p = 0.066$ and $p = 0.065$ respectively), while other differences are not statistically significant.

The above results regarding treatment IA do confirm our Prediction 2 partially, however, IS performing the worst and IAS performing the best violate our Prediction 2 and 3. The reasons are twofold. On one hand, the S players in IA do not babble as the theory predicts, but they inflate the message about threshold value in general which will be discussed further in the next part. On the other hand, the receives are less strategic and are more credulous. These two factors together make the coordination in IAS much easier. Furthermore, the inflated message helps the R players to *"overcome"* the equal cost share principal and be able to contribute more and provide more public goods when the threshold level is low. In contrast, players in IS cannot find a rule of thumb to facilitate their coordination. It seems that a large proportion of players does not have the capacity to reason about the equilibrium play so they rely heavily on obvious focal points to coordinate at, and they fail to coordinate when such focal points are absent.

Figure 2(f) shows the public goods provided conditional on successful provision which lends some support to the above argument. It shows that, conditional on successful provision, the mean public goods provided in treatments CS, IA, and IS are not significantly different from each other (42.2, 43.5, and 42.1 respectively). Compare with Figure 2(c) we should know that the underperformance in treatments IS and IA is mainly due to mis-coordination which dues to the lack of an obvious focal point to coordinate at. Furthermore, the mean public goods provided conditional on successful provision in IAS (47.7) is significantly higher than that in the other three treatments ($p = 0.012$, $p = 0.077$, and $p = 0.047$ respectively) which is consistent with significantly higher contributions elicited in IAS.

Result 2: *The IAS treatment elicits the highest contribution, provides the highest public goods, and delivers the highest social welfare in general. The IS and IA treatments perform the worst due to the lack of an obvious focal point to coordinate at.*

Regression Results

Table 4 are results of regressions with dependent variables of contribution, provision ratio, public goods provided, inefficiency caused by wasted contribution, welfare, and public goods provided conditional on successful provision respectively. Columns (1), (3), (4), (5), and (6) are OLS regressions with period fixed effect and robust standard errors clustered at the group level, while column (2) presents logit regression results.

Table 4: Regression Results on Various Variables

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent Var.	Contribution	Pro_Ratio	Provided	Inefficiency	Welfare	Prov_Cond
CS	-1.298	-0.039	-4.057	-0.003	-4.055	-5.878^{**}
	(0.908)	(0.406)	(5.121)	(2.753)	(7.697)	(2.442)
IS	-3.039^{***}	-0.752^{**}	-10.468^{**}	2.367	-12.836^{**}	-4.860^{**}
	(1.102)	(0.329)	(4.210)	(2.102)	(5.755)	(2.401)
IA	-3.164^{***}	-0.872^{**}	-12.669^{***}	2.595	-15.264^{**}	-6.672^{***}
	(1.184)	(0.360)	(4.431)	(2.224)	(6.187)	(2.320)
MPCR	6.533^{***}	1.969^{***}	28.534^{***}	-8.935^{**}	37.469^{***}	14.875^{***}
	(1.688)	(0.705)	(8.191)	(4.433)	(12.160)	(4.702)
Agreeableness	Yes	Yes	Yes	Yes	Yes	Yes
Other Covariate	Yes	Yes	Yes	Yes	Yes	Yes
Period F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Num. obs.	7440	7440	7440	7440	7440	3999
R^2	0.079		0.080	0.020	0.051	0.122
Adj. R^2	0.074		0.076	0.015	0.046	0.114
Pseudo R^2		0.036				

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$. Robust standard errors clustered at group level are presented in parenthesis. `Agreeableness` includes measurements of six facets of agreeableness which are trust, morality, altruism, cooperation, modesty, sympathy, and `Other Covariate` includes gender, age, nationality, risk preference, past experience of participating in lab experiments, past experience with game theory, and a binary variable `Order` which equals 1 if subjects experience $\rho = 0.6$ first and 0 otherwise. A `Period` fixed effect is also included in all regressions.

The regression results are pretty consistent with our above results obtained via nonparametric tests and thus support our Result 2. It is significant that IAS performs better than IA and IS according to various standards, and potentially better than CS in terms of providing more public goods when they are successfully provided.

Another thing to note is that MPCR is a significant predictor in all regression results. Specifically, an increase in MPCR significantly increases levels of contribution, provision ratio, public goods provided, and welfare, while it reduces inefficiency caused by wasted contribution, thus, the effect of an increase in MPCR in our experiment is consistent with the literature (see Holt & Laury, 2008, for a review). In order to see a cleaner effect of MPCR within each treatment, we run regressions on contribution and individual profit within each treatment, and the results are presented in Table 8 and 9 in Appendix A. The regression results show a consistent and significant MPCR effect in treatments CS, IS, and IAS, however, it does not have any significant effect in IA where asymmetric information is present without any communication mechanism.[25]

Result 3: *Except for treatment IA where asymmetric information is present without any communication mechanism, an increase in the MPCR value significantly boosts contribution and the ratio of successful provision of public goods.*

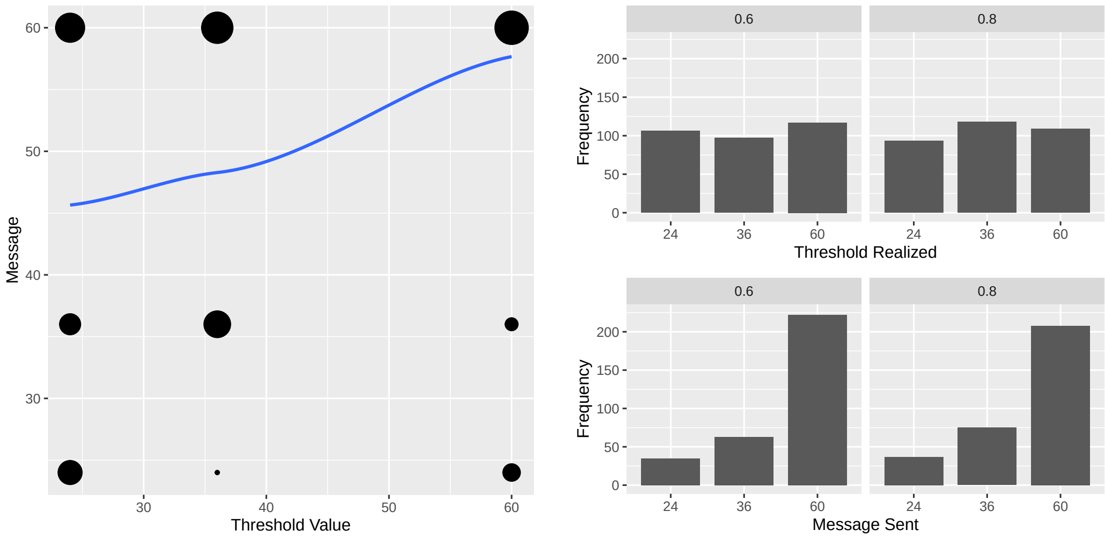
Given the robust superiority of IAS compared with other treatments, it is necessary to look at the S player's messaging and contributing strategy as well as the R players', and one important concern is whether IAS delivers higher welfare on average at the cost of a higher level of inequality. In the next section, we are going to address this issue.

5.3 S player Behavior and Inequality Across Treatments

There might be a higher level of inequality among the players in IAS than the others because of information asymmetry which grants the S player an advantageous position. Therefore, we first look at the S player's messaging strategy and then examine the inequalities in individual profits among players in different treatments.

Figure 3(a) shows that the S players over-report the threshold level, however, there is also a non-negligible portion of S players who truthfully reports the threshold level which is represented by the size of the dots on the 45° line. Figure 3(b) shows the distribution of both realized threshold levels and reported messages with respect to different MPCR values. The over-reporting strategy appears to be robust against the MPCR change in our experiment. This further raises the concern that R players under IA might be taken

[25]Though we do not have any evidence-based explanation for this, we suspect that subjects are very reluctant to contribute when information asymmetry is present, and there is no (communication) mechanism that can ease this asymmetry to some extent. As a result, this effect is dominant and subjects do not respond to MPCR changes.



(a) Messaging Strategy

(b) Distribution of θ and m

Figure 3: S player's Messaging Strategy under IA

advantage of and thus result in overall poor welfare status.

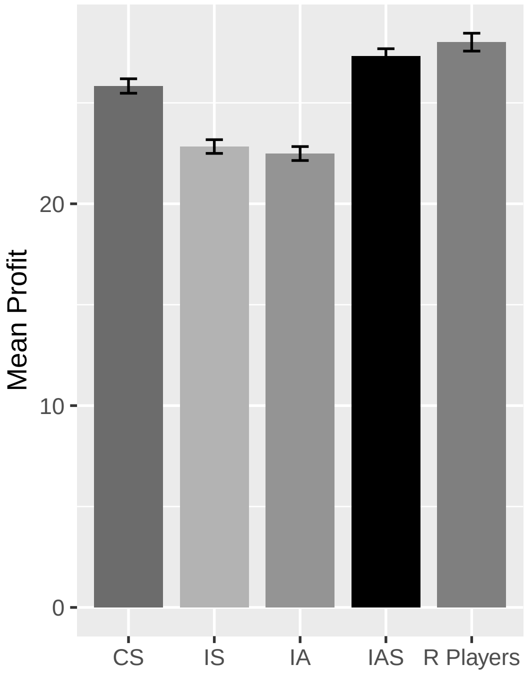
We address this concern by first comparing the R players' mean profit in treatment IAS with that in all other treatments, and then comparing the mean Gini index across all the treatments. Specifically, If the R players' mean profit is less than that in IAS, then IAS increases inequality among players though it yields a higher level of welfare on average. However, Figure 4(a) shows that this is not the case. The R players' mean profit in IAS (represented by 'R Players") is not lower than that in IAS as a whole which implies that IAS delivers a Pareto improvement compared with other treatments. In addition, the mean profit in IAS (27.31) is significantly higher than that in IS (22.84, $p = 0.055$) and CS (22.49, $p = 0.039$). Although it is also higher than that in CS (25.83), the difference is not statistically significant.

Figure 4(b) compares the mean Gini index across the four treatments, and it shows that the mean Gini index in IAS (0.205) is roughly the same as that in the CS treatment (0.212, $p = 0.426$). In addition, it is not significantly higher than that in either CS or IS ($p = 0.574$ and $p = 0.961$ respectively). To sum up, we have the following result.

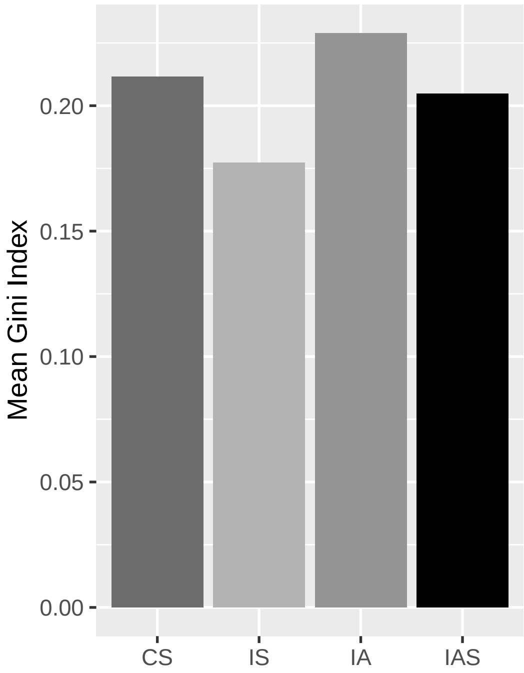
Result 4: *While IAS induces the highest level of contribution and welfare, it does not come at the cost of a higher inequality level. The overall economic performance in IAS Pareto dominates that in IS and IA.*

Table 5 shows the contributions in IAS for each role with respect to either the true threshold level θ or the message sent by the S player M. The first thing to notice is that the S players' contributions are generally higher than the R players' (except for $M = 24$).

From Figure 3 we know that S players tend to inflate θ when it is low, however, Table 5 demonstrates that they do not take advantage of others by (partially) free-riding on others. In addition, they also increase



(a) Profit Including Receivers under IA



(b) Gini Index Across Treatments

Figure 4: Mean Profits, Gini Index, and Inequality Across Treatments

their own contributions when they inflate θ, which can be seen by comparing the mean contributions between $\theta = 24$ and $m = 24$ (or between $\theta = 36$ and $m = 36$). Notice that the S players' mean contribution under $\theta = 60$ is slightly lower than that under $m = 60$, and this dues to the fact that they occasionally underreport θ when it is 60.[26] Nonetheless, their mean contribution is also higher than the R players'.

Result 5: *Although the S players often inflate θ by sending $m > \theta$, they also increase their own contributions when they inflate. Thus, their intention is mainly to achieve public good provision to the maximum likelihood but not to take advantage of the R players.*

[26]We suspect that they underreport when they feel that it is hard to achieve public goods provision under $\theta = 60$ and then give it up in that period, thus, they send a lower m to mislead others less since public goods are not going to be provided anyway. This can be seen as white lies that are well-documented by Erat and Gneezy (2012).

Table 5: Contributions in IAS w.r.t. Role and θ or m

	$\theta = 24$		$\theta = 36$		$\theta = 60$	
	Mean	SD	Mean	SD	Mean	SD
S player	14.3	(6.90)	15.2	(5.99)	16.3	(7.66)
R players	12.2	(8.05)	13.0	(7.70)	14.4	(8.38)
	$m = 24$		$m = 36$		$m = 60$	
S player	9.31	(6.32)	12.1	(5.84)	17.4	(6.38)
R players	10.7	(6.31)	11.6	(6.28)	14.2	(8.69)

Notice that this can not be attributed to the S players' incentive to lead-by-example. First, the contribution decisions are made simultaneously thus there is no room to lead-by-example in the current period. Second, no feedback is provided at the end of each period thus there is no room to lead-by-example between periods. Providing no information feedback at the end of each period also precludes the possibility of reciprocity. One possible explanation is that the S players are altruistic towards others and thus are willing to contribute more.[27] A regression on the S player's contribution shows that `Altruism` is a significant predictor (please see Table 10 for details). However, altruistic preference alone cannot explain the messaging strategy taken by S, since one can be altruistic and truth-telling at the same time. The S players are being altruistic while trying to achieve a higher level of public goods provision, i.e., they are trying to achieve a Pareto improvement at least for the group.

6 Conclusion and Discussion

We economists normally (intuitively) think that an environment with complete and thus symmetric (CS) information would deliver the best economic outcome since each agent can fully optimize without paying any informational rent to anyone else. The incomplete and symmetric information structure would be worse since each agent optimizes with incomplete (maybe wrong) constraints. The incomplete and asymmetric information structure would be the worst since additional informational rent would be charged by those who have more information.

However, in a simple threshold public goods game with three different information structures about the threshold value (CS, Complete and Symmetric; IS, Incomplete and Symmetric; IA, Incomplete and Asymmetric), the theory predicts something counterintuitive: the IS information structure performs the best, followed by the CS information structure, and with the IA information structure (and IAS with communication) performs the worst.

Our experimental results confirm the conventional conjecture on the effectiveness of information structures in promoting cooperation and coordination. The performance in IS and IA are the worst among the three, and CS elicits higher levels of contribution, public goods provided, and welfare, although the difference is not significant. Notice that the theoretical prediction of the superiority of IS over other information structures requires a very high order of cognitive power for the subjects in IS which might not be true. In addition, our results suggest that subjects tend to coordinate at an obvious focal point no matter whether it is directly observed or notified by a non-verifiable message, however, subjects do not have such an obvious focal point in IS and IA.

Furthermore, the presence of signaling in treatment IA facilitates cooperation and coordination

[27] Players might also receive some psychological utility from being altruistic which is documented as impure altruism by Andreoni (1989, 1990), and Ottoni-Wilhelm, Vesterlund, and Xie (2017) further provide evidence for impure altruism.

tremendously by sending a non-verifiable message regarding θ which serves as an obvious focal point to coordinate for the R players. Although the S players inflate θ by sending $m > \theta$, they also increase their own contributions when they inflate θ, therefore, a Pareto improvement is achieved: significant higher levels of contribution, provision ratio, public goods provided, and welfare, especially compared with IS and IA. A regression analysis of the S players' contribution shows that Altruism and Trust are significant predictors of higher contributions, and the S players do not respond to an MPCR change which implies that their strategy is to maximize the likelihood of public goods provision.

On the other hand, the R players tend to be trusting towards the message sent by S, and they consider it as a focal point to facilitate their coordination and cooperation. This is consistent with the literature that receivers in cheap talk games exhibit a certain kind of credulity towards those non-verifiable messages. This credulity together with the S players' inflation on θ yields higher contributions than the required threshold level and thus provides a higher level of welfare. Please note that the rebate rule is important for higher performance in IAS in our experiment. Without the rebate rule, excess contributions do not provide more benefits and thus the results in IAS might be different.

This further sheds light on how we can achieve economically desirable outcomes - economic optimality. Traditionally, economic optimality is achieved with the assumptions of complete information and economic agents with full calculating capacity and stable decision rules that are not affected by any psychological factors. Therefore, we try to promote information transparency and liberal education on economics and finance so that our economic agents would make decisions more often according to our expectations. Unfortunately, neither the information can be complete nor the agent can be a *Homo economicus*. Alternatively, the results obtained in this paper suggest another way: By cultivating a certain set of attributes of our economic agents — more trusting and altruistic towards others — information asymmetry is not detrimental at all when a simple restricted signaling mechanism is presented. In a cooperation and coordination problem similar to the one examined in this paper, IA with signaling can produce significantly better economic outcomes than that under incomplete information (symmetric or asymmetric), and it produces one that is at least as good as the one produced under complete information. Following this insight, we can design institutions to institutionalize some concepts, social norms, or cultural values that enhance trust and altruistic preference. Lastly, these two ways of achieving economically desirable outcomes can be complementary to each other.

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Appendix A Extra Tables & Figures

Table 6: Descriptive Statistics of Contribution

Mean & SD		CS0.6	CS0.8	IAS0.6	IAS0.8	IS0.6	IS0.8	IA0.6	IA0.8
MPCR = 0.6	K = 24	9.76	10.68	11.45	13.22	11.48	9.24	12.14	9.52
		(6.28)	(6.51)	(7.93)	(8.14)	(7.43)	(6.78)	(7.30)	(7.75)
	K = 36	11.33	12.68	12.45	13.48	11.36	9.43	12.85	10.98
		(7.06)	(6.44)	(7.45)	(7.94)	(7.03)	(7.14)	(7.14)	(7.54)
	K = 60	13.91	14.47	14.51	14.92	10.52	7.81	13.14	7.12
		(9.19)	(8.98)	(8.32)	(8.50)	(7.44)	(7.52)	(8.25)	(8.01)
	Pool	11.60	12.64	12.85	13.93	11.09	8.80	12.64	9.11
		(7.74)	(7.42)	(8.02)	(8.24)	(7.31)	(7.17)	(7.38)	(7.93)
MPCR = 0.8	K = 24	10.54	12.47	12.63	14.22	13.17	12.08	13.89	9.63
		(6.37)	(6.15)	(7.62)	(7.01)	(7.32)	(6.32)	(6.82)	(7.64)
	K = 36	12.69	13.83	13.34	15.53	13.50	12.36	13.62	8.50
		(6.30)	(5.42)	(6.78)	(6.65)	(7.22)	(6.40)	(7.13)	(7.93)
	K = 60	14.78	15.60	16.29	14.45	13.17	11.73	12.97	7.66
		(8.81)	(8.31)	(7.12)	(8.68)	(7.21)	(5.86)	(8.57)	(8.40)
	Pool	12.45	13.97	14.19	14.75	13.29	12.09	13.50	8.67
		(7.33)	(6.86)	(7.28)	(7.50)	(7.24)	(6.22)	(7.53)	(7.99)
Pool Over MPCR		12.03	13.30	13.52	14.34	12.19	10.45	13.07	8.89
		(7.55)	(7.17)	(7.68)	(7.88)	(7.35)	(6.90)	(7.52)	(7.96)
Pool Over All		12.62		13.93		11.32		11.12	
		(7.40)		(7.79)		(7.18)		(8.00)	

Table 7: Descriptive Statistics on Provision Ratio

Provision Ratio (%)		CS0.6	CS0.8	IS0.6	IS0.8	IAS0.6	IAS0.8	IA0.6	IA0.8
MPCR = 0.6	K = 24	76.8	92.5	73.6	69.5	69.8	90.6	0.83	0.60
	K = 36	37.7	69.5	50.0	32.6	68.0	68.1	0.58	0.45
	K = 60	35.3	24.4	1.7	0	21.1	38.3	0.03	0
	Pool	50.6	62.9	40.0	35.0	51.9	64.4	0.54	0.34
MPCR = 0.8	K = 24	88.9	91.5	77.8	85.5	71.4	100	0.98	0.63
	K = 36	51.0	80.4	66.1	54.1	62.9	89.3	0.69	0.28
	K = 60	39.1	42.6	14.0	4.5	51.8	30.2	0.09	0
	Pool	62.5	71.4	61.2	73.1	53.8	51.3	0.59	0.33
Pool Over MPCR		56.6	67.1	46.9	43.1	56.6	68.8	0.57	0.33
Pool Over All		61.5		45.0		62.7		45.8	

Table 8: Regressions on Contribution Within Each Treatment

	Dependent variable: Contribution			
	(1)	(2)	(3)	(4)
	CS	IS	IA	IAS
MPCR	5.358**	13.698***	1.283	5.391*
	(2.457)	(4.098)	(3.292)	(2.912)
Trust	0.053	0.364**	0.269	0.551**
	(0.182)	(0.127)	(0.236)	(0.196)
Morality	0.031	−0.343*	−0.380	−0.277
	(0.247)	(0.193)	(0.235)	(0.303)
Altruism	−0.665**	0.206	0.347	0.200
	(0.257)	(0.183)	(0.273)	(0.362)
Cooperation	−0.155	−0.358*	0.202	0.256
	(0.211)	(0.203)	(0.191)	(0.299)
Modesty	0.313	0.087	−0.011	−0.164
	(0.194)	(0.145)	(0.197)	(0.188)
Sympathy	0.445	0.088	−0.257	−0.260
	(0.289)	(0.164)	(0.201)	(0.347)
Other Covariate	Yes	Yes	Yes	Yes
Period F.E.	Yes	Yes	Yes	Yes
Num. obs.	1800	1920	1800	1920
R^2	0.126	0.271	0.216	0.158
Adj. R^2	0.111	0.259	0.202	0.144

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$. Robust standard errors clustered at group level are presented in parenthesis. `Other Covariate` includes gender, age, nationality, risk preference, past experience of participating in lab experiments, past experience with game theory, and a binary variable `Order` which equals 1 if subjects experience $\rho = 0.6$ first and 0 otherwise. A `Period` fixed effect is also included in all regressions.

Table 9: Regressions on Individual Profit Within Each Treatment

	Dependent variable: Profit			
	(1)	(2)	(3)	(4)
	CS	IS	IA	IAS
MPCR	40.944***	38.246***	10.857	45.816***
	(8.919)	(11.745)	(10.534)	(10.077)
Trust	−0.192	0.144	−0.374	−0.096
	(0.230)	(0.193)	(0.244)	(0.288)
Morality	0.324	0.253	0.149	0.144
	(0.505)	(0.282)	(0.250)	(0.320)
Altruism	0.448	0.269	−0.383	0.583
	(0.490)	(0.209)	(0.331)	(0.492)
Cooperation	0.276	−0.194	−0.365	−0.939*
	(0.248)	(0.223)	(0.225)	(0.483)
Modesty	−0.378	−0.420*	−0.006	0.244
	(0.327)	(0.200)	(0.204)	(0.221)
Sympathy	−0.152	0.107	0.682***	0.313
	(0.601)	(0.189)	(0.218)	(0.533)
Other Covariate	Yes	Yes	Yes	Yes
Period F.E.	Yes	Yes	Yes	Yes
Num. obs.	1800	1920	1800	1920
R^2	0.170	0.118	0.142	0.172
Adj. R^2	0.155	0.104	0.126	0.158

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$. Robust standard errors clustered at group level are presented in parenthesis. `Other Covariate` includes gender, age, nationality, risk preference, past experience of participating in lab experiments, past experience with game theory, and a binary variable `Order` which equals 1 if subjects experience $\rho = 0.6$ first and 0 otherwise. A `Period` fixed effect is also included in all regressions.

Table 10: Regression on The S Player's Contribution

	Dependent variable: Contribution
MPCR	1.403
	(2.426)
Trust	0.377^{**}
	(0.153)
Morality	-0.168
	(0.284)
Altruism	0.562^{*}
	(0.287)
Cooperation	0.179
	(0.254)
Modesty	0.001
	(0.212)
Sympathy	-0.551^{**}
	(0.265)
Other Covariate	Yes
Period F.E.	Yes
Num. obs.	1240
R^2	0.208
Adj. R^2	0.187

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$. Robust standard errors clustered at group level are presented in parenthesis. `Other Covariate` includes gender, age, nationality, risk preference, past experience of participating in lab experiments, past experience with game theory, and a binary variable `Order` which equals 1 if subjects experience $\rho = 0.6$ first and 0 otherwise. A `Period` fixed effect is also included in all regressions.

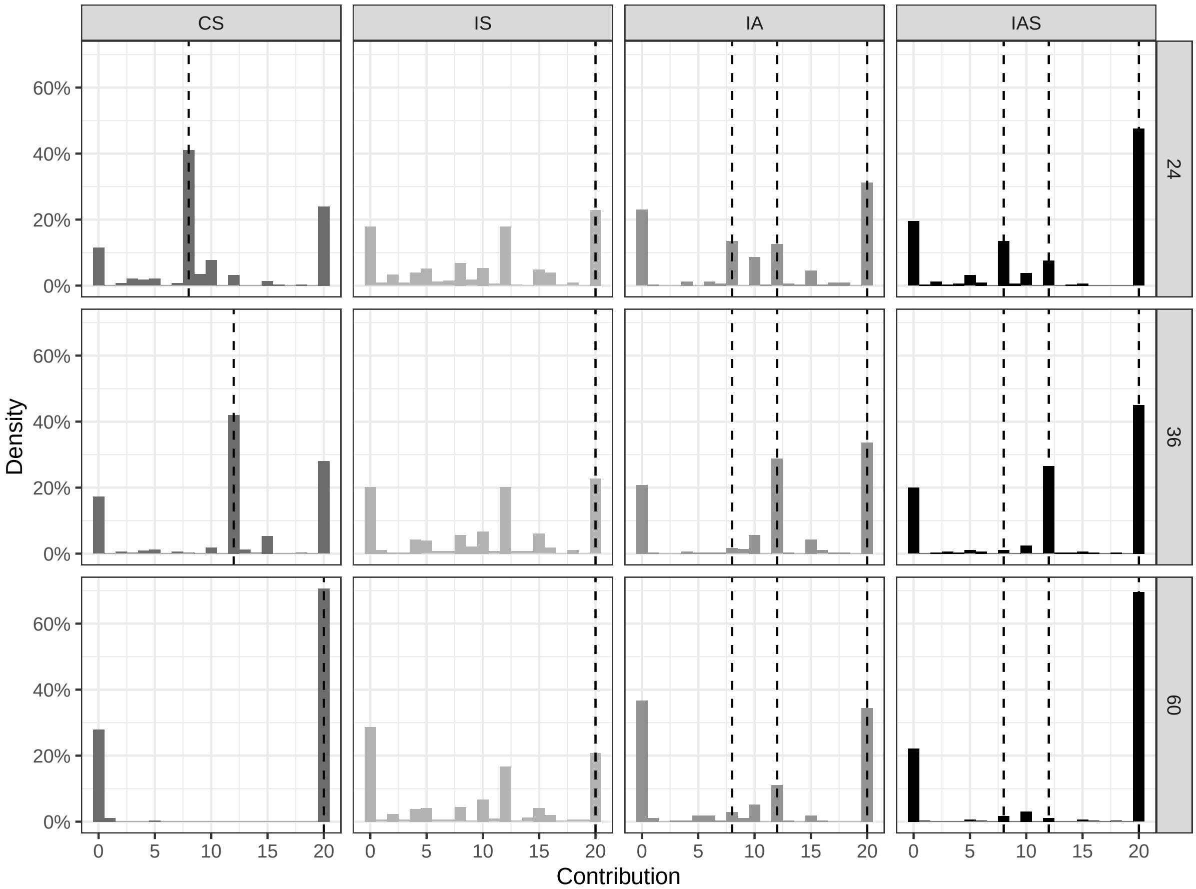

Figure 5: Distribution of Contribution When MPCR = 0.6

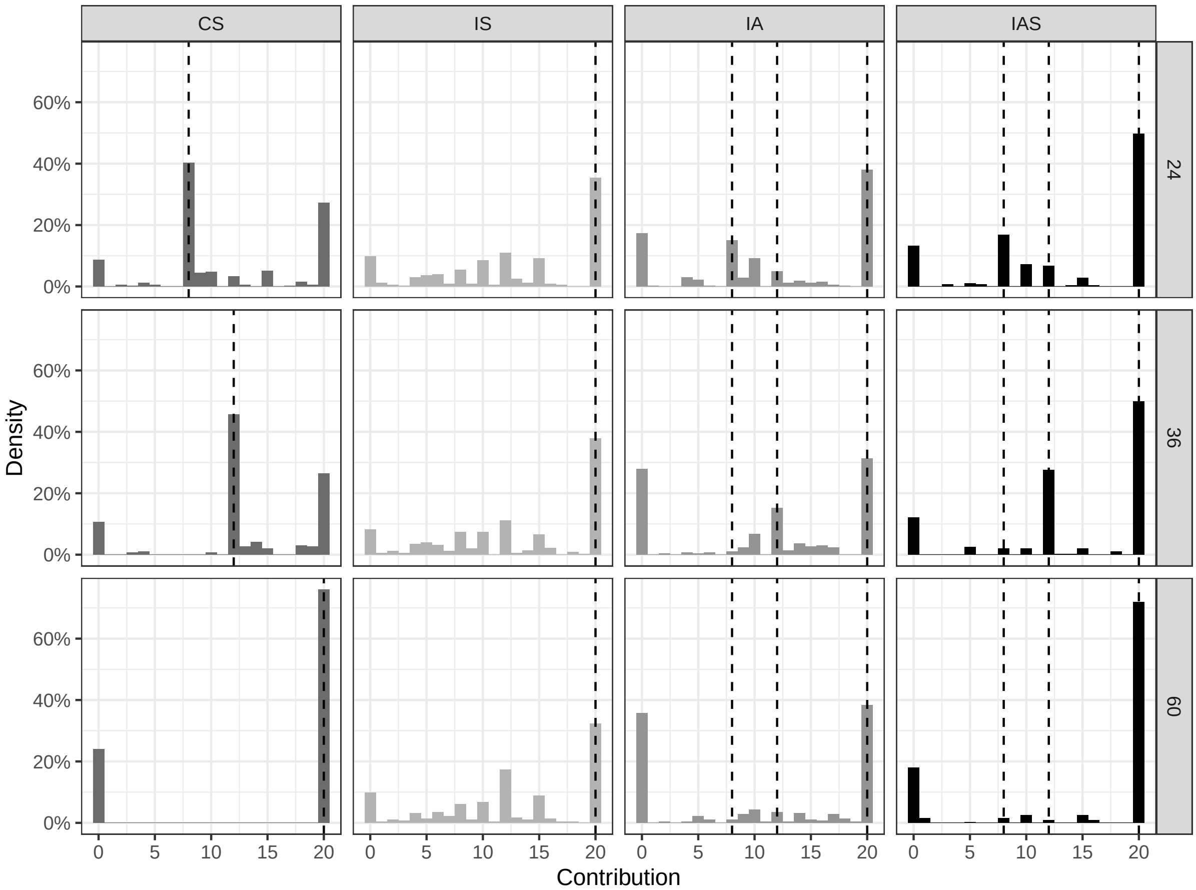

Figure 6: Distribution of Contribution WhenMPCR = 0.8

Appendix B Proofs & Derivations

Proposition 1: Under complete and symmetric information, for each $\theta \in \Theta$, there is a unique NE where each player contributes $\frac{\theta}{N}$, $\forall\, \theta \in \Theta$.

Proof: It is straightforward with Assumption 1. Q.E.D.

Proposition 2: $\forall\, \theta_k \in \Theta$, $\theta_k \in \Theta^*_{IS}$ if and only if the following conditions are satisfied:

$$\theta_k(1-\rho\sum_{i=1}^{k} p_i) \leqslant \theta_f(1-\rho\sum_{i=1}^{f} p_i), \qquad \forall\, f \in \{k+1,\cdots,K\}$$

$$\rho\theta_k\sum_{i=0}^{k} p_k - \frac{\theta_k}{N} \geqslant \rho\left(\frac{(N-1)\theta_k}{N} + a_{i,g}\right)\sum_{i=0}^{g} p_i - a_{i,g}, \qquad \forall\, g \in \{0,\cdots,k-1\}$$

Proof: One would deviate his contribution upwardly only when public goods can be provided at higher level of θ, as a result, he would increase his contribution just enough to provide public goods when the state of world is θ_f with $k < f \leqslant K$. Since the cost of deviation is $\theta_f - \theta_k$ and the benefit is $\rho\theta_f\sum_{i=1}^{f} p_i - \rho\theta_k\sum_{i=1}^{k} p_i$, one has no incentive to deviate upwardly if and only if $\theta_f - \theta_k \geqslant \rho\theta_f\sum_{i=1}^{f} p_i - \rho\theta_k\sum_{i=1}^{k} p_i$, i.e.,

$$\theta_k(1-\rho\sum_{i=1}^{k} p_i) \leqslant \theta_f(1-\rho\sum_{i=1}^{f} p_i)$$

If one deviates his contribution downwardly, he would decrease his contribution just enough to provide public goods when the state of world is θ_g with $1 \leqslant g < k$. There are two cases to consider here: (i) $\theta_g \leqslant \frac{(N-1)\theta_k}{N}$, so he does not have to contribute anything in order to achieve public goods provision; (ii) $\theta_g > \frac{(N-1)\theta_k}{N}$, so he needs to contribute the margin $\left(\theta_g - \frac{(N-1)\theta_k}{N}\right)$ in order to achieve public goods provision at θ_g. Combine them together, one would decrease his contribution to $\max\left(0,\, \theta_g - \frac{(N-1)\theta_k}{N}\right) \equiv a_{i,g}$. Thus, coordinating at θ_k might be a NE if the following inequality holds:

$$\mathbb{E}(U_i) = E - \frac{\theta_k}{N} + \rho\theta_k\sum_{i=1}^{k} p_k \geqslant E - a_{i,g} + \rho\left(\frac{(N-1)\theta_k}{N} + a_{i,g}\right)\sum_{i=1}^{g} p_i$$

A special case to be checked is that the player decides to sit on his endowment and no public goods are provided, thus, we define $\theta_0 = p_0 = 0$ and $a_{i,0} = 0$ to cover this case. Therefore, the conditions that coordinating at θ_k is a NE for each player can be unified and summarized in the position.

Q.E.D.

Lemma 1: $\forall\, \theta_k \in \Theta^*_{IA}$, each R player would contribute $\frac{\theta_k}{N}$, and the S player's best response is to contribute $I(a_s(\theta_T,\theta_k))a_s(\theta_T,\theta_k)$.

Proof: $\forall\, \theta_k \in \Theta^*_{IA}$, all the R players consider that it is in equilibrium to coordinate at θ_k together with the S player, based on the focal point implied by Assumption 1, each R player would contribute $\frac{\theta_k}{N}$ and expecting the S player to contribute $\frac{\theta_k}{N}$ as well.

However, the S player does not necessarily contribute $\dfrac{\theta_k}{N}$ as the R players expect, and her contribution strategy depends on both θ_k and the observed state θ_T. If $\theta_T = \theta_k$, it is also in equilibrium for the S player to coordinate at θ_k and thus contribute $\dfrac{\theta_k}{N}$. However, if $\theta_T \neq \theta_k$, the S player would vary her contribution to maximize her expected utility, and her best response is further specified as follows:

1. if $\theta_T < \theta_k$, she chooses $a_s(\theta_T, \theta_k) \equiv \max\left(0,\, \theta_T - \dfrac{(N-1)\theta_k}{N}\right)$ to achieve public goods provision;
2. if $\theta_T > \theta_k$, she only contributes if public goods provision can be achieved and it is beneficial for her to do so which are translated to the the following two conditions: (i) $\theta_T - \dfrac{(N-1)\theta_k}{N} \leqslant E$ so she is able to make the contribution required to reach θ_i; (ii) $\theta_T - \dfrac{(N-1)\theta_k}{N} \leqslant \rho\theta_T$ so she benefits from successful provision of public goods. Combining them together, she would only contribute $\theta_T - \dfrac{(N-1)\theta_k}{N}$ if and only if $\theta_T - \dfrac{(N-1)\theta_k}{N} \leqslant \min\left(E,\, \rho\theta_T\right)$, and nothing otherwise.

Let us define an indicator function $I(a_s(\theta_T, \theta_k)) \equiv I\left(a_s(\theta_T, \theta_k) \leqslant \min(E,\, \rho\theta_T)\right)$ which takes the value of 1 if the condition in the parenthesis is satisfied and 0 otherwise. The above results can be summarized as that the S player's best response is to contribute $I(a_s(\theta_T, \theta_k))a_s(\theta_T, \theta_k)$.

Q.E.D.

Proposition 3: $\forall\, \theta_k \in \Theta,\ \theta_k \in \Theta^*_{IA}$ if and only if the following conditions are satisfied:

$$\begin{aligned} &\mathbb{E}(U_R(\theta_k)) \geqslant \mathbb{E}(U_R(\theta_f)), && \forall\, \theta_f \in \Theta_f \\ &\mathbb{E}(U_R(\theta_k)) \geqslant \mathbb{E}(U_R(\theta_g)), && \forall\, \theta_g \in \Theta_g \end{aligned}$$

Proof: Given the S player's best response described in Lemma 1, we only need to investigate whether each R player has an incentive to deviate in order to determine whether $\theta_k \in \Theta^*_{IA}$. Each R player's expected utility function is as follows:

$$\mathbb{E}(U_R(\theta_k)) = E - \frac{\theta_k}{N} + \rho \sum_{i=1}^{K} p_i I(a_s(\theta_i, \theta_k)) \left(a_s(\theta_i, \theta_k) + \frac{(N-1)\theta_k}{N}\right) \tag{10}$$

$I(a_s(\theta_T, \theta_k)) = 1$ selects all the θ_T at which public goods are successfully provided given all R players consider that it is in equilibrium to coordinate at θ_k.

Similarly, each R player can deviate his contribution either upwardly or downwardly. Note that the S player's contribution is $I(a_s(\theta_T, \theta_k))a_s(\theta_T, \theta_k)$ which varies according to the θ_T she observes. Suppose the deviated R player increases his contribution just enough to provide public goods when the state of world is θ_f with $k < f \leqslant K$, and we must have $I(a_s(\theta_f, \theta_k)) = 0$, otherwise, the provision of public goods is already achieved with the S player contributing the required margin. Thus, the R player has to increase his contribution to $\theta_f - \dfrac{(N-2)\theta_k}{N} \equiv a_{r,f}$ in order to provide public goods at θ_f. Define $\Theta_f = \{\theta_f \,|\, \theta_f \in \Theta,\, I(a_s(\theta_f, \theta_k)) = 0, a_{r,f} \leqslant E\}$, and $\forall \theta_f \in \Theta_f$, the R player's expected utility after deviation is described as follows:

$$\mathbb{E}(U_R(\theta_f)) = E - a_{r,f} + \rho \sum_{i=1}^{f} p_i \left(\theta_f + I(a_s(\theta_i, \theta_k))a_s(\theta_i, \theta_k)\right) \tag{11}$$

Therefore, each R player has no incentive to deviate his contribution upwardly if and only if $\mathbb{E}(U_R(\theta_k)) \geqslant \mathbb{E}(U_R(\theta_f)),\ \forall\, \theta_f \in \Theta_f$.

Now let's consider the case where one R player deviates his contribution downwardly. As long as

$\left(\theta_g - \dfrac{(N-1)\theta_k}{N}\right) \geqslant 0$, the S player has to make a non-negative contribution to achieve public goods provision,[28] and there is no excess contributions at state θ_g. As a result, any deviation would result in a failure in public goods provision at state θ_g. Therefore, the R player would only deviate to the set of θ_g with $\left(\theta_g - \dfrac{(N-1)\theta_k}{N}\right) < 0$, thus, he has to contribute the margin $a_{r,g} \equiv \max\left(0, \theta_g - \dfrac{(N-2)\theta_k}{N}\right)$ to achieve public goods provision. Define $\Theta_g \equiv \{\theta_g \,|\, \theta_g \in \Theta, \theta_g - \dfrac{(N-1)\theta_k}{N} < 0, a_{r,g} \leqslant E\}$, and $\forall \theta_g \in \Theta_g$, the deviated R player's expected utility is described as follows:

$$\mathbb{E}(U_R(\theta_g)) = E - a_{r,g} + \rho\left(a_{r,g} + \frac{(N-2)\theta_k}{N}\right)\sum_{i=0}^{g} p_i \tag{12}$$

As a result, any R player has no incentive to deviate his contribution downwardly if and only if $\mathbb{E}(U_R(\theta_k)) \geqslant \mathbb{E}(U_R(\theta_g)), \forall \theta_g \in \Theta_g$. Combine the above conditions together, we have the above proposition.

Q.E.D.

Proposition 4: In equilibrium, the S player's messaging strategy is always babbling, i.e., $\Theta^*_{IAS} = \Theta^*_{IA}$.

Proof: A pooling pure strategy PBE, i.e., the babbling equilibrium, will always exist. When the S player is babbling, no information is actually transmitted which is the same as the IA case without the messaging mechanism, and thus $\Theta^*_{IAS} = \Theta^*_{IA}$.

We then examine whether there is a fully separating pure strategy PBE. Suppose the S player is always truth-telling,[29] so she always sends a message $m = \theta$. Therefore, she and all the R players consider that it is in equilibrium (also optimal) to coordinate at θ. According to Assumption 1, each of them would contribute $\dfrac{m}{N} = \dfrac{\theta}{N}$. Since the R players only get to know the message m, the S player does have an incentive to send a message $m > \theta$ so that all R players would contribute $\dfrac{m}{N}$ and she only needs to make up the margin $\theta - \dfrac{(N-1)m}{N}$ which is definitely smaller than $\dfrac{\theta}{N}$ when $m > \theta$. Therefore, truth-telling is never going to be the messaging strategy in equilibrium.

Next we consider whether there is a partial pooling pure strategy equilibrium. $\forall m_l \in M \equiv \{m_1, ..., m_L\} \subseteq \Theta, \forall \theta \in \Theta$, the S player's messaging strategy is characterized by $\mu(m_l|\theta)$ with $\sum_l \mu(m_l|\theta) = 1$. All R players then form their posteriors $\alpha(\theta|m_l)$ according to Bayes' rule.

Let us use Θ^*_l to denote the associated set of θ at which coordination is in equilibrium if the R players hold posteriors $\alpha(\theta|m_l)$ after receiving message m_l given μ. If $\Theta^*_l \neq \emptyset$, for any $\theta_{l_j} \in \Theta^*_l$ at which the R players coordinate in equilibrium, let us denote S player's expected utility as $\mathbb{E}(U_S(\theta_{l_j}))$, and it would be different for different θ_{l_j}. Suppose that each $\theta_{l_j} \in \Theta^*_l$ will be implemented as a successful coordination with equal probability in equilibrium, then S player's expected utility of sending m_l according to μ is $\mathbb{E}(U_S(m_l)) = \sum_{\theta_{l_j} \in \Theta^*_l} \mathbb{E}\left(U_S(\theta_{l_j})\right)/n\left(\Theta^*_l\right)$ where $n\left(\Theta^*_l\right)$ is the cardinality of the set Θ^*_l.

Suppose $\exists m_1, m_2 \in M$, and the associated equilibrium set Θ^*_1 and Θ^*_2 yields different expected utility for the S player, and suppose $\mathbb{E}(U_S(m_1)) < \mathbb{E}(U_S(m_2))$. Given the fact that, conditional on successful coordination, S always prefers a higher expected contribution from the R players irrespective of θ_T, she will deviate her messaging strategy from μ by switching from m_1 to m_2, therefore, this cannot be the

[28]When $\left(\theta_g - \dfrac{(N-1)\theta_k}{N}\right) = 0$, the S player does not have to contribute anything, and the public goods are just provided with each receiver's contribution at $a_r = \dfrac{\theta_k}{N}$.

[29]It is equivalent to any perfectly separating messaging strategy as message encoding is irrelevant.

case in equilibrium.

Therefore, $\forall m_l \in M$, the induced S player's expected utility $\mathbb{E}(U_S(m_l))$ is the same. The S player is indifferent to babbling.

Q.E.D.

Derivation of the equilibrium strategies in the parametric example

Consider the parametric example where $N = 3$, $E = 20$, $\Theta = \{\theta_1 = 24, \theta_2 = 36, \theta_3 = 60\}$, and $\mathbb{P} \equiv \{p_1 = p_2 = p_3 = 1/3\}$.

Under CS, according to Proposition 1, players' equilibrium strategy is to contribute $\theta/3, \forall\, \theta \in \Theta$.

Under IS, according to Proposition 2, coordinating at $\theta_1 = 24$ (so each player contributes 8) is an equilibrium if any R player cannot benefit by deviating either upwardly or downwardly:

$$\begin{cases} 24\left(1 - \rho \times \dfrac{1}{3}\right) \leqslant 36\left(1 - \rho \times \dfrac{2}{3}\right) & \Longrightarrow \quad \rho \leqslant 0.5 \\ 24\left(1 - \rho \times \dfrac{1}{3}\right) \leqslant 60\,(1 - \rho \times 1) & \Longrightarrow \quad \rho \leqslant \dfrac{36}{52} \approx 0.69 \\ 20 - \dfrac{24}{3} + \dfrac{1}{3} \times 24\rho \geqslant 20 & \Longrightarrow \quad \rho \geqslant 1 \end{cases}$$

Therefore, coordinating at $\theta_1 = 24$ can never be an equilibrium since any R player can benefit from deviating his contribution upwardly or downwardly for any ρ.

Similarly, we can get that coordinating at $\theta_2 = 36$ is not an equilibrium for any ρ, and $\theta_3 = 60$ if and only if $\rho \geqslant 0.6$.

Under IA and IAS, when the R players decide to coordinate at $\theta_1 = 24$, according to Lemma 1, the S player would contribute $I(a_s(\theta_1, \theta_i))a_s(\theta_1, \theta_i)$, $\forall \theta_i \in \Theta$. It is easy to get that $a_s(\theta_1, \theta_1) = 8$, and $I(a_s(\theta_1, \theta_1)) = 1$ for any $\rho \in (0.33, 1)$; $a_s(\theta_1, \theta_2) = 20$, and $I(a_s(\theta_1, \theta_2)) = 1$ if and only if $\rho \geqslant 5/9 \approx 0.56$; $a_s(\theta_1, \theta_3) = 44$, and $I(a_s(\theta_1, \theta_3)) = 0$ for any ρ. Therefore, public goods are provided with $\theta_1 = 24$ and $\theta_2 = 36$.

Next we have $\Theta_f = \emptyset$ since $a_{r,3} = \theta_3 - 24/3 > 20$, and $\Theta_g = \{\theta_0\}$. Therefore, according to Proposition 3, coordinating at $\theta = 24$ constitutes an equilibrium if and only if the following condition is met:

$$20 - \frac{24}{3} + \rho \sum_{i=1}^{3} p_i I(a_s(\theta_1, \theta_i)) \left(a_s(\theta_1, \theta_i) + \frac{(3-1) \times 24}{3} \right) \geq 20 \tag{13}$$

Since $I(a_s(\theta_1, \theta_2))$ is dependent on ρ, the above condition has to be solved case by case according to ρ. When $\rho \in (0.33, 0.56)$, the condition holds when $\rho \geqslant 1$ which violates our assumption on ρ. When $\rho \in [0.56, 1)$, the condition holds if $\rho \geqslant 0.4$. Therefore, coordinating at $\theta_1 = 24$ can be an equilibrium if and only if $\rho \in [0.56, 1)$.

Similarly, we can have that coordinating at $\theta_2 = 36$ is an equilibrium if and only if $\rho \geqslant 0.6$, and $\theta_3 = 60$ if and only if $\rho \geq 0.43$.

Appendix C A Sample Experimental Instruction: IAS

General Information

You are now taking part in an interactive study on decision making. **Please pay attention to the information provided here and make your decisions carefully. If at any time you have questions to ask, please raise your hand and we will attend to you in private.**

Please note that unauthorized communication is prohibited. Failure to adhere to this rule would force us to stop the experiment and you may be held liable for the cost incurred in this experiment. You have the right to withdraw from the experiment at any point, and if you decide to do so your payoff earned during this study will be forfeited.

By participating in this study, you will be able to earn a considerable amount of money. The amount depends on the decisions you and others make.

At the end of this session, this money will be paid to you privately and in cash. It would be contained in an envelope which is indicated with your unique subject ID. You will need to sign a receipt form to acknowledge that you have been given the correct amount.

General Instructions

Each of you will be given a unique subject ID at the beginning of the experiment. Your **anonymity will be preserved** for the study. You will **never be aware of** the personal identities of other players **during or after** the study. Similarly, other players will also **never be aware of** your personal identities **during or after** the study. You will only be identified by your subject ID in our data collection. All information collected will **strictly be kept confidential** for the sole purpose of this study.

Your earnings in the experiment are denominated by "**Experimental Currency Unit(s)**" or "**ECU(s)**". At the end of the experiment, they will be converted into Singapore Dollars at the rate of

1 ECU = 0.1 SGD.

The real-dollar equivalent of your final earnings will be added to your **show-up fee** as your final payoff and paid to you privately in cash at the end of the experiment.

Specific Instructions

You will participate in **three** stages, the specific instructions will be given to you at the beginning of each stage. The following is the specific instruction for stage one.

Stage One

Welcome to Stage One of our experiment. In this part of the experiment, you will **form a group of three** randomly with two other participants, and **the group composition will remain the same** throughout this experiment.

As a group, you are going to play an investment game for 20 periods. At the beginning of each period, each group member will be given an endowment of **20 ECUs**. Your decision is to **choose an amount X** out of your endowment (any number between 0 and 20, including 0 and 20) to invest in a group project and **keep the rest** $(20 - X)$ **privately**. The total investments made by you and your group members are denoted as X_{Total}.

The group project will be **successfully implemented** if the total investments (X_{Total}) are **NOT LESS** than **K** (ECUs), where K is a threshold value that is randomly drawn from **{24, 36, 60}** in each period. Therefore, K **has equal chance**, which is 1/3, to be 24, or 36, or 60 in each period. Note that the value of K can be different or the same from period to period.

The profitability coefficient $\mathbf{P = 1.8}$ defines how profitable your group project is. Once the group project is successfully implemented, the **total investments** X_{Total} **will be multiplied by this profitability coefficient 1.8**, and then distributed **equally** among you and your group members. Therefore, each member will get $X_{Total} \times 1.8 \div 3$ from the group project.

Taken together, you are left with $(20 - X)$ after you invested X into the group project. In addition to the amount you keep privately, you can get benefits from the group project depending on its implementation status. In case that $X_{Total} \geqslant K$, so the group project is successfully implemented, each member gets $(X_{Total} \times 1.8 \div 3)$ from the group project. In case that $X_{Total} < K$, the project is not successfully implemented, and **all the investments are gone**.

Therefore, your earning in each period is as follows:

- If $X_{Total} \geqslant K$, your earning is $(20 - X) + (X_{Total} \times 1.8 \div 3)$.
- If $X_{Total} < K$, your earning is $(20 - X)$.

For example, suppose that you invest 10 ECUs in the project (so $X = 10$), and the total investments in the project by all your group members including you are 30 ECUs (so $X_{Total} = 30$). If $K = 24$, then the project will be successfully implemented because $X_{Total} > K$ (as $30 > 24$), and your earning is $(20–10) + (30 \times 1.8 \div 3) = 28$ (ECUs). If $K = 36$, then the project will not be successfully implemented because now $X_{Total} < K$, and your earning in this period is $(20–10) = 10$ (ECUs).

As to the threshold value, **only one member in your group** will be informed of the value of K at the beginning of each period, and he/she is **randomly selected** among the three of you. Therefore, **each participant has 1/3 chance** to be selected as the person who will know the value of K in private throughout Stage One. Therefore, the value of K is a **private information** that **only the selected member knows**.

The selected member then needs to **send a message about the value of K to the rest of the group in each period.** After the message is received, all group members will make the investment decision X (how much you would like to invest in the group project).

For example, suppose the selected member observes that the threshold value $K = 36$, he/she then needs to send a message of 24 or 36 or 60 telling the other two group members that the threshold value is 24 or 36 or 60.

There are a few test questions before Stage One actually starts. You have to answer all of them correctly in order to proceed. There is a calculator at the bottom left corner of your screen in case you need it. Please raise your hand if you have any questions.

At the end of the experiment (after Stage Three), **two out of 20 periods** in this stage will be randomly selected and **the sum of your earnings in these periods will be your total earnings in Stage One**, which will be added to your final earnings from this experiment when the experiment is completed. Then you will be shown on your screen **your earnings and the implementation status** of your group project in each period in Stage One as well as the two periods that are selected. Since you do not know which periods are going to be selected, **the best strategy is to take each period equally important.**

Stage Two

In Stage Two, you are going to play the same game as you've played in Stage One for another 20 periods with only one change: Now the **profitability coefficient P = 2.4**. The group composition remains unchanged. Therefore, your earning in each period in Stage Two becomes:

- If $X_{Total} \geqslant K$, your earning is $(20 - X) + (X_{Total} \times 2.4 \div 3)$.
- If $X_{Total} < K$, your earning is $(20 - X)$.

For example, suppose that you invest 10 ECUs in the project (so $X = 10$), and the total investments in the project by all your group members including you are 30 ECUs (so $X_{Total} = 30$). If $K = 24$, then the project will be successfully implemented because $X_{Total} > K$ (as $30 > 24$), and your earning is $(20–10) + (30 \times 2.4 \div 3) = 34$ (ECUs). If $K = 36$, then the project will not be successfully implemented because now $X_{Total} < K$, and your earning in this period is $(20–10) = 10$ (ECUs).

The same as in Stage One, **only the same selected member in Stage One** will be informed of the value of K at the beginning of each period in Stage Two. He/she also needs to **send a message about the value of K to the rest of the group.** After the message is received, all members in your group needs to make an investment decision X (how much you would like to invest in the group project).

There are a few test questions before Stage Two actually starts. You have to answer all of them correctly in order to proceed. Please bear in mind that **the only difference of Stage Two from Stage One is the profitability coefficient P which equals 2.4 now.**

At the end of the experiment (after Stage Three), **two out of 20 periods** in this stage will be randomly selected and **the sum of your earnings in these periods will be your total earnings in Stage Two**, which will be added to your final earnings from this experiment when the experiment is completed. Then you will be shown on your screen **your earnings and the implementation status** of your group project in each period in Stage Two as well as the two periods that are selected. Since you do not know which periods are going to be selected, **the best strategy is to take each period equally important.**

Stage Three

In Stage Three, you will be asked to make a series of choices. How much you receive will depend partly on chance and partly on your own choices. The decision problems are not designed to test you. What we want to know is **what choices you would make** in them. The only right answer is what you really would choose.

For each of the ten lines in the table on the computer screen, please state whether you prefer **Option L** or **Option R**. Table 1 below is an example of what you will see on your computer screen later on. **Option L** gives you a sure amount of 20 ECUs, while **Option R** gives you either 40 ECUs or nothing with different chances in different lines. Take Line 1 as an example, **Option R** gives you 40 ECUs with 10% chance, and nothing with 90% chance, while **Option L** gives you 20 ECUs for sure.

In Line 1, if you think 10% chance of getting 40 ECUs is better than getting 20 ECUs for sure, then you would choose **Option R**. If not, you would choose **Option L**. Notably, as you go down the table from Line 1 to Line 10, the value of **Option L** keeps constant, while the average value of **Option R** increases as the chance of getting 40 ECUs increases. In particular, **Option R** in Line 10 gives you 40 ECUs with 100% chance.

Table 11: Option Task

Line	Option L (ECUs)	Option R (ECUs)	Your Choice
1	20	(40 with 10% chance, 0 with 90% chance)	
2	20	(40 with 20% chance, 0 with 80% chance)	
3	20	(40 with 30% chance, 0 with 70% chance)	
4	20	(40 with 40% chance, 0 with 60% chance)	
5	20	(40 with 50% chance, 0 with 50% chance)	
6	20	(40 with 60% chance, 0 with 40% chance)	
7	20	(40 with 70% chance, 0 with 30% chance)	
8	20	(40 with 80% chance, 0 with 20% chance)	
9	20	(40 with 90% chance, 0 with 10% chance)	
10	20	(40 with 100% chance, 0 with 0% chance)	

Notice that there are a total of ten lines in the table but **just one line** will be randomly selected for your earning. Since you do not know which line will be paid when you make your choices, **you should pay attention to the choice you make in every line.** After you have completed all your choices, the computer will randomly choose a line to be paid with equal chance of 1/10 for each line.

Your earning for the selected line depends on which option you chose: If you chose **Option L** in that line, you will receive **20 ECUs**. If you chose **Option R** in that line, you will receive **either 40 ECUs or 0** with the **chances stated in Option R**, which will be executed by a computer program.

Your earning in Stage Three will be added to your final earnings from this experiment when the experiment is completed.

This is the end of the specific instructions for each stage.

Final Payoff

For your reference, your **total earnings** in this experiment would be the sum of the following parts:

1. Total earnings of **Two randomly chosen binding periods** in Stage One.
2. Total earnings of **Two randomly chosen binding periods** in Stage Two.
3. Earning in Stage Three.

Your total earnings will then be converted to S$ and added to your **show-up fee as your final payoff** in this experiment. You will be paid privately according to your unique subject ID.

Thank you again for your participation! If you have any questions, please raise your hand and an experimenter will come to you.