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DOCTORAL THESIS

Essays in Public Economics

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Abstract

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The thesis consists of three chapters in public economics. In the first two chapters, we develop theoretical models to show how citizens' tax evasion and the governor's embezzlement affect public good provision. In the third chapter, I design an experiment to see how position uncertainty in a sequential public goods game affects contribution levels.

In the first chapter, we consider a model that links tax evasion, corruption, and public good provision. In our model, citizens pay or evade taxes into the public fund, which a corrupt governor redistributes. Each citizen forms expectations about the amount of public goods the governor should provide. After observing the actual level of public goods, a citizen punishes the governor if this level is below his expectations. We describe three types of equilibria: tax evasion, efficient public good provision, and symmetric mixed-strategy. We show that the highest expectations can lead to no free-riding (tax evasion) and the efficient level of public good provision even with the corrupt governor and without punishment for tax evasion.

The second chapter complements the first chapter by relaxing the assumption of symmetric strategy. In this chapter, we consider a model with two citizens and a governor. First, the citizens decide whether to pay tax or evade. Then, Nature (an independent tax authority) audits one of the citizens randomly, and in case of non-payment, the citizen is fined and are forced to pay the tax. Third, the governor receives the taxes and decides how much public good to provide. Finally, after the governor's decisions, citizens observe the amount of public good provided and express their opinion on whether the governor embezzled from the public fund or not. More specifically, the citizens guess the correct number of units in the public fund. We formulate this in a four-stage extensive form game. We characterise the Bayesian Nash Equilibrium of this game. Our main result shows that any strategy profile can be a Nash equilibrium for the

right choice of the parameter. This suggests that, as a society, we could reach a particular set of outcomes if we set specific restrictions on the parameters (for example, we can set parameters such that there is no tax evasion). By assuming that citizens care about their guesses (i.e. opinions) we can refine our Nash predictions. This gives us three different types of Nash equilibrium. First, we show that if the penalty for evading tax is too low, then both citizens have an incentive to evade tax. Then, we show that if the penalty for evading tax is high enough, and the penalty for embezzlement is low then at least one of the citizens pays tax and the governor embezzles whenever he has the opportunity to do so. Finally, we show that if the penalty for both embezzlement and tax evasion is high enough, we will have efficient public good provision, meaning all citizens pay tax and the governor uses the entire fund to provide the public good.

Finally, in the third chapter, I design an experiment to see how position uncertainty in a sequential public goods game affects the level of the contributions. Theory suggests that in a one-shot game among a finite number of self-interested individuals, full cooperation is sustainable (Gallice & Monzón, 2019). This prediction is completely different from the previous theoretical predictions. The experiment consists of two treatments. The first treatment is a sequential public goods game. The second treatment is the game with position uncertainty. The results show that the contributions, at the group level, in each treatment are statistically different.

Declaration

I hereby declare that except where specific reference is made to the work of others, the contents of this dissertation are original and have not been submitted in whole or in part for consideration for any other degree or qualification in this, or any other university.

I confirm that chapters 1 and 2 are jointly co-authored with Prof. Alexander Matros and Dr. Sonali Sen Gupta. A version of chapter 1 has been submitted to a journal.

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Chapter 1

Public Good Provision : A Tale of Tax Evasion and Corruption

1.1 Introduction

Tax is a mandatory financial charge levied upon citizens to fund public expenditures including the provision of public goods. A citizen's decision of whether or not to pay taxes not only depends on monetary reasons, but also on several non-monetary factors. These include social norms, peer pressure, trust in government and political corruption. In most societies, elected political leaders (mayors, governors, etc.) control the public funds and decide how to redistribute them. Empirical evidence shows that political corruption (such as embezzlement of public funds by governmental officials for private gain) exists both in developed and developing countries, see, for example, Costas-Pérez et al. (2012), Ferraz and Finan (2008), Reinikka and Svensson (2004). However, there is a surprising lack of study on the connections among tax evasion, political corruption, and public good provision.

In this chapter, we develop a theoretical model to show how citizens' tax evasion and the governor's embezzlement affect public good provision. The main problem of public good provision is free riding. In our model, each citizen decides whether to evade taxes and free ride on public goods or not. The governor collects taxes in the public fund and decides how to allocate it. The governor is corrupt and behaves in her own self interests: she embezzles public funds if her benefits outweigh her costs. Even though the free rider problem is magnified by the corrupt governor in our model, we show that this governor in fact helps to obtain the efficient public good provision even without punishments for tax evasion.

There are two types of punishments in the model. First, each citizen can be punished for the tax evasion with a positive probability. Tax authorities can only monitor a certain fraction of citizens and so this probability is typically less than one. Moreover, each citizen forms expectations about public good provision and if the actual provision is below these expectations, then the citizen punishes the governor. Empirical evidence shows that indeed citizens tend to punish by not re-electing corrupt politicians, see, for example Ferraz and Finan (2011), Welch and Hibbing (1997).

We obtain three main results in the model. First, the efficient public good provision equilibrium is characterized. We show that if the punishment for embezzlement of public funds is high enough, then there exists an equilibrium where all citizens pay taxes and expect the efficient public good provision from the governor. If this provision is not provided by the governor, then all citizens punish her. This leads to a situation where the governor either provides the efficient level of public goods if she collects enough funds or she embezzles all public funds because she is punished for all other levels of public good provision. In this situation each citizen is pivotal for public good provision and the efficient level of public good provision can be achieved without punishment for tax evasion.

Note that citizens' expectations of the public good provision are a measure of accountability for the elected politician (the governor in our model), and so these expectations can prevent embezzling of public funds. Accountability has been widely studied in political science and political economy literature (see, for example, Duggan and Martinelli (2017), Maskin and Tirole (2004), Persson et al. (1997)) with the emphasis on elections and organizational structures. Instead of focusing on political accountability, in this chapter, we focus on social accountability. According to the World Bank, "while the concept of social accountability remains contested, it can broadly be understood as a range of actions and strategies beyond voting, that societal actors – namely the citizens – employ to hold the state to account" (O'Meally, 2013). Citizens could use a multitude of social accountability mechanisms to put pressure and hold public officials or/and elected politician accountable. When citizens perceive their rights to be violated and/or there are inadequate goods and services provided, they challenge the government. Some examples of social accountability measures include the monitoring and oversight of public sector performance, protesting, complaints and claim-making.[1] For example, India has a long history of the formal mechanism of complaint and claim-making called "grievance redress mechanism" (Auerbach & Kruks-Wisner, 2020; Post & Agarwal, 2011). The central idea of the mechanism is that in the case that the citizens' expectations for a certain level of public goods or services are not met, the citizens can complain to a government agency and hold the officials accountable. The officials concerned are required to respond to such a complaint. This further encourages citizens to make official complaints, which creates a positive feedback loop.

Second, as in any public good game, the tax evasion equilibrium is characterized. We show that if the punishment for tax evasion is relatively small, then all citizens can evade taxes and expect the minimal level of the public good provision from the governor, who in turn always provides the minimal level of public goods. Note that the citizens' expectations are always correct and self-enforced in this equilibrium.

Finally, we show that for any citizens' expectations, there always exists a (mixed-strategy) equilibrium, where the governor matches these expectations: she either provides exactly the expected level of public good if she collects enough funds or embezzles all public funds if she does not collect enough funds to match the expectations.

There is a lot of literature on tax evasion, embezzlement, and public goods. Each topic deserves its own special attention. Allingham and Sandmo (1972), in their seminal paper, analyze an individual taxpayer's decision. The individual decides how much of their income to declare to the tax authority with a given tax rate and a fixed probability of audit. Since then, the literature on tax evasion has expanded. See Slemrod (1985), Slemrod and Yitzhaki (2002), and Alm (2019) for a review of the tax evasion literature.

Corruption and embezzlement are extensively studied both by economists and political scientists. See, for example, Ades and Di Tella (1999), Brollo et al.

[1] See Fox (2015) for a meta-analysis on social accountability.

(2013), Weitz-Shapiro and Winters (2017), Welch and Hibbing (1997), where corrupt behavior of a ruler is punished by individual population members via elections.

The literature on public goods started from Samuelson (1954). See also Chaudhuri (2011), Ledyard (1995) for reviews. The recent work is focused on improving the mechanism of redistributing public funds and decreasing the free rider problem. A peer punishment (i.e. decentralised or informal punishment), see Fehr and Gächter (2000, 2002), as well as, a central sanction mechanism, see Andreoni and Bergstrom (1996), Baldassarri and Grossman (2012), Markussen et al. (2014, 2016), have been used to tackle the free rider problem.

Even though the literature on tax evasion, corruption and public good provision is vast, only a handful of papers look into the interplay between them. Lambert-Mogiliansky (2015) links public good provision, corruption and social accountability by considering a model where a public official allocates a budget for public goods and services, and the official has to provide evidence that she deserves to be reappointed, or else she will be suspected of embezzlement. In this chapter, we use citizens' complaints as a social accountability mechanism.[2] Another related work that connects public good provision, corruption and (political) accountability is Van Weelden (2013), where an infinitely repeated citizen-candidate model of political competition is used to study the corrupt behavior of the elected politician. The elected candidate chooses the policy to implement and how much to embezzle when in office. The voter decides which candidate to elect and, subsequently, whether the candidate should be retained. Our focus in this chapter is on social accountability.

Litina and Palivos (2016) link embezzlement and tax evasion via a theoretical framework consisting of an overlapping generation of citizens and politicians, where a fraction of the population emerges as politicians through a random process. The model uses social stigma as a way to deter corrupt behaviour. In our model, citizens live for the entire game (i.e. no overlapping generation of citizens) and the governor is distinct from the citizens. More importantly, we

[2] See Bobonis et al. (2016), Avis et al. (2018), Campante and Do (2014), Ortner and Chassang (2018) for some recent literature on various other accountability mechanisms for reducing corruption.

focus on deterrence policies like the enforcement mechanisms for both citizens (penalty for tax evasion) and politicians (citizens' complaints).

The outline of the chapter is as follows: Section 1.2 describes our model. Section 1.3 presents the analysis of the model that includes the main results, a discussion of these results. We conclude in Section 1.4.

1.2 Model

We consider a four-stage sequential-move game involving $N = \{1, 2, 3, .., n\}$ citizens and a governor, G. First, citizens decide whether or not to pay taxes. Then, Nature - an independent tax agency, like IRS in the USA or HMRC in UK, which acts as a non-strategic player of the game - selects $k \leq n$ citizens to audit at random. If the audited citizen did not pay tax, then he has to pay it and is also penalized. The total tax collected goes into a public fund which the governor redistributes in the form of public goods. The governor keeps (embezzles) whatever is left in the public fund after the redistribution. Finally, citizens voice their opinion about the governor by punishing the latter in the case of lower provision of public goods than what they expected. We will formally describe the game now.

Stage 1

Each citizen $i \in N$ simultaneously chooses an action t_i, where $t_i = 0$ $(= 1)$ implies tax evasion (tax payment). We assume that the tax is 1 unit for each citizen and the total tax collected goes towards the public fund.

Stage 2

Nature randomly selects k (out of n) citizens to audit, and we assume

$$Pr(\text{citizen } i \text{ is audited}) = \frac{k}{n}.$$

If a non-tax paying citizen is audited, he will need to pay 1 unit of tax and a penalty for tax evasion, z, where $z \geq 0$. Taxes and penalties go to the 'Consolidated Fund Account', out of which total penalty pays for supply services, i.e.

payments issued to government departments, like IRS and HMRC, to finance their expenditure, and taxes go towards the public fund.[3]

Stage 3

The governor receives total public funds $X \in \{k, k+1, ..., n\}$. If all citizens evade taxes, the governor receives $X = k$ units of the public fund, while the maximum amount of the public fund available to the governor is $X = n$ (for example if all citizens pay taxes).

The governor can choose to redistribute any amount, $g \leq X$, from the public fund. In this case, each citizen receives ag and the governor gets $ag + (X - g)$, where $0 < a < 1$ is the marginal per capita return from the public good. We assume that the governor also benefits from the public good provision.

Stage 4

In the final stage of the game, we model a proxy for voting, where each citizen i forms expectations, $\tau_i \in \{k, k+1, ..., n\}$, of the total public fund X available to the governor. Citizens observe the level of public good, g, being provided by the governor, and in the case $g < \tau_i$, citizen i punishes the governor by $b \geq 0$ for not meeting his expectations, in other words, the governor loses the confidence of her citizens. We assume that citizens care about having the right expectations and putting across their opinion in the case when their expectations are not met. We assume that a citizen i gets some disutility if $\tau_i > g$ and he does not complain. This assumption means that each citizen has a dominant action at stage 4. Our results also hold if we assume that only a particular share of citizens behave that way. Figure 1.1 summarizes the four stages of the game.

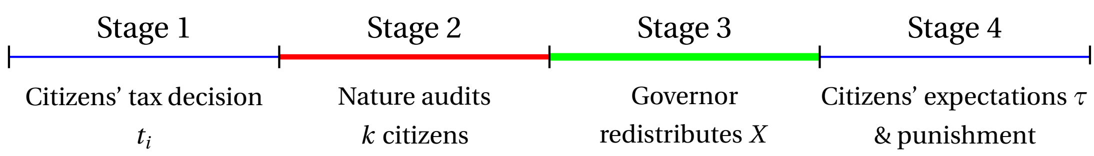

Figure 1.1: Timeline

[3]See, for example, page 2 of Treasury (2018).

We can describe the payoffs of all players after stage 4 now. Citizen i receives

$$u_i((1,\tau_i),...;g) = ag - 1,$$

where the citizen paid tax, the governor provided g units of public goods, and citizen i expected τ_i units of public goods from the governor. Analogously, citizen i receives

$$u_i((0,\tau_i),...;g) = \begin{cases} ag, & \text{if } i \text{ was not audited,} \\ ag - 1 - z, & \text{if } i \text{ was audited,} \end{cases}$$

where the citizen evaded tax, the governor provided g units of public goods, and citizen i expected τ_i units of public goods from the governor.

Utility for the governor is

$$u_G((1,\tau_1),...,(0,\tau_n);g) = X - g + ag - [\#\text{complaints}]b,$$

where the total public fund is X, the governor provided g units of public goods, citizen i expected τ_i units of public goods from the governor, and [#complaints] is the number of citizens whose public good expectations are above g.

1.3 Analysis

Citizens and the governor have many pure strategies in the model. However, it is enough to consider only particular strategies to obtain our main results. So, we will restrict our attention to symmetric pure strategies for citizens and cut-off strategies for the governor.

Symmetric pure strategies $(1,\tau)$ and $(0,\tau)$ specify whether citizens pay taxes, 1, or not, 0, and τ describes their public good provision expectations. Since citizens have the dominant action at stage 4, they complain if $\tau > g$ and they do not complain if $\tau \leq g$. We will also consider symmetric mixed strategies $\sigma = (p,\tau)$ where citizens randomize over the first stage actions, pay taxes with probability p, and expect τ units of public goods.

A cutoff strategy $\langle g \rangle$ means that the governor redistributes exactly $g \geq 0$ units if the total collected public fund is at or above this cutoff level, or $g \leq X$. Otherwise, no public good is produced. Note that the governor, who uses the cutoff strategy, embezzles public funds more often than not. For example, she plunders whatever is left in the public fund after the cutoff level is satisfied. It is even more striking that we obtain our results with a corrupt governor.

We will be looking for symmetric (pure and mixed) equilibria in this section. Our results take into account an important element of the model – citizens' expectations, τ. In the next Lemma 1, we characterize these expectations, assuming that citizens are rational.

LEMMA 1.1. *Suppose that there are n citizens and k of them are audited. If each citizen pays 1 unit tax with probability p at stage 1, then the expected number of units, τ, that the governor collects is*

$$\tau = k + p(n-k). \tag{1.1}$$

Proof of Lemma 1.1. Let j denote the number of citizens paying tax. Let k_s denote the number of successful audits. Let K be a random variable whose outcome is k_s. Here K follows a hyper-geometric distribution whose probability mass function (p.m.f) is given by

$$Pr(K = k_s) = \frac{\binom{j}{k-k_s}\binom{n-j}{k_s}}{\binom{n}{k}} \tag{1.2}$$

Let τ represent the expected number of units that the governor has.

$$
\begin{aligned}
\tau &= \sum_{j=0}^{n}\sum_{k_s=0}^{k}(j+k_s)\binom{n}{j}p^j(1-p)^{n-j}\frac{\binom{j}{k-k_s}\binom{n-j}{k_s}}{\binom{n}{k}} \\
&= \sum_{j=0}^{n}\binom{n}{j}p^j(1-p)^{n-j}\left(\sum_{k_s=0}^{k}(j+k_s)\frac{\binom{j}{k-k_s}\binom{n-j}{k_s}}{\binom{n}{k}}\right) \\
&= \sum_{j=0}^{n}\binom{n}{j}p^j(1-p)^{n-j}\left(\sum_{k_s=0}^{k}j\frac{\binom{j}{k-k_s}\binom{n-j}{k_s}}{\binom{n}{k}}+\sum_{k_s=0}^{k}k_s\frac{\binom{j}{k-k_s}\binom{n-j}{k_s}}{\binom{n}{k}}\right) \qquad (1.3)
\end{aligned}
$$

We apply *absorption identity* (Graham et al., 1994, p. 157) on the last term of (1.3) and we get the following

$$
\tau = \sum_{j=0}^{n}\binom{n}{j}p^j(1-p)^{n-j}\left(\sum_{k_s=0}^{k}j\frac{\binom{j}{k-k_s}\binom{n-j}{k_s}}{\binom{n}{k}}+\sum_{k_s=1}^{k}(n-j)\frac{\binom{j}{k-k_s}\binom{n-j-1}{k_s-1}}{\binom{n}{k}}\right) \qquad (1.4)
$$

Then we use *Vandermonde's identity* on the last two terms in (1.4)

$$
\begin{aligned}
\tau &= \sum_{j=0}^{n}\binom{n}{j}p^j(1-p)^{n-j}\left(j\frac{\binom{n}{k}}{\binom{n}{k}}+(n-j)\frac{\binom{n-1}{k-1}}{\binom{n}{k}}\right) \\
&= \sum_{j=0}^{n}\binom{n}{j}p^j(1-p)^{n-j}\left(j+(n-j)(\frac{k}{n})\right) \\
&= \sum_{j=0}^{n}(j)\binom{n}{j}p^j(1-p)^{n-j}+k\sum_{j=0}^{n}\binom{n}{j}p^j(1-p)^{n-j}-\frac{k}{n}\sum_{j=0}^{n}(j)\binom{n}{j}p^j(1-p)^{n-j} \\
&= \sum_{j=1}^{n}(n)\binom{n-1}{j-1}p^j(1-p)^{n-j}+k(1)-\frac{k}{n}\sum_{j=1}^{n}(n)\binom{n-1}{j-1}p^j(1-p)^{n-j} \\
&= \sum_{j=1}^{n}(np)\binom{n-1}{j-1}p^{j-1}(1-p)^{n-j}+k(1)-\frac{k}{n}\sum_{j=1}^{n}(np)\binom{n-1}{j-1}p^{j-1}(1-p)^{n-j} \\
&= np+k-kp \\
&= k+p(n-k) \qquad (1.5)
\end{aligned}
$$

□

Next, we analyze three situations. First, we consider *efficient public good provision*, where each citizen pays the tax, $p = 1$, and expects, from Lemma 1, $\tau = n$ units of public goods from the governor, who provides exactly n units in the equilibrium. The second situation we look at is a *tax evasion equilibrium*, where each citizen does not pay the tax, $p = 0$, and expects, from Lemma 1, $\tau = k$ units of public good from the governor, who indeed provides k units in the equilibrium. In order to give a flavor of these results, we consider an example describing these two extreme cases in the next subsection 1.3.1.

Finally, we analyze a situation when each citizen pays the tax with probability p and expects, from Lemma 1, τ units of public goods from the governor, who provides either τ units, if she collects enough taxes, or 0 units, if she receives less than τ units in taxes. We illustrate this result in subsection 1.3.4.

Our results depend on the four parameters of the model: marginal per capita return a, punishment for embezzlement b, penalty for tax evasion z, and citizens' expectations about the public fund, τ.

1.3.1 An example

In this section, we present an example that illustrates our two main findings. Suppose that there are $n = 3$ citizens and one of them is audited at random, $k = 1$. We also assume that $a = \frac{3}{4}$, $b = \frac{1}{2}$, and $z = 1$.

Efficient public good provision

Consider a situation when each citizen pays $t = 1$ unit tax, or $p = 1$, and expects, from Lemma 1, $\tau = 3$ units of public good from the governor, or plays strategy $(p, \tau) = (1, 3)$. Suppose that the governor redistributes g units, using a cutoff strategy

$$g = \langle 3 \rangle = \begin{cases} 0, & \text{if } X < 3, \\ 3, & \text{if } X = 3, \end{cases}$$

where the total collected public fund is X, and if it is at the cutoff level, 3, then the governor produces exactly 3 units of public goods. Otherwise, no public good is produced.

We claim that a symmetric strategy profile $((1,3),(1,3),(1,3);\langle 3 \rangle)$ is a Nash equilibrium. Let us verify that. Note that the expected utility of citizen i is

$$E\,u_i((1,3),(1,3),(1,3);\langle 3 \rangle) = 3a - 1 = \frac{5}{4},$$

and the expected governor's utility is

$$E\,u_G((1,3),(1,3),(1,3);\langle 3\rangle) = 3a = \frac{9}{4}.$$

For the strategy profile $((1,3),(1,3),(1,3);\langle 3\rangle)$ to be a pure strategy Nash equilibrium, it should be mutual best responses for the players to play the strategy prescribed in the profile. The best possible deviation for the governor is to embezzle all units from the public fund, which gives the following expected utility:

$$E\,u_G((1,3),(1,3),(1,3);\langle 0\rangle) = 3-3b = \frac{3}{2} < E\,u_G((1,3),(1,3),(1,3);\langle 3\rangle).$$

The best possible deviation for citizen $i = 1$ is to evade taxes, and the corresponding expected utility is

$$E\,u_i((0,3),(1,3),(1,3);\langle 3\rangle) = \frac{1}{3}(3a-z-1)+\frac{2}{3}(0) = \frac{1}{12} < E\,u_1((1,3),(1,3),(1,3);\langle 3\rangle).$$

Note that if citizen $i = 1$ evades the tax and is not audited, the governor gets only 2 units in taxes and, therefore, embezzles these 2 units, because she will be punished for not providing 3 units of the public good by two other citizens who expect three units of public goods. Thus, given our parameter values, the strategy profile $((1,3),(1,3),(1,3);\langle 3\rangle)$ is a Nash equilibrium. We generalize this result in Theorem 1 (see subsection 1.3.2).

Tax evasion

Consider a situation when each citizen evades taxes, or $p = 0$, and expects, from Lemma 1, $\tau = k = 1$ units of public good from the governor, or plays strategy $(p,\tau) = (0,1)$. Suppose that the governor redistributes $g = 1$ unit, which is always possible because $k = 1$. Then, a symmetric strategy profile $((0,1),(0,1),(0,1);\langle 1\rangle)$ is a Nash equilibrium. Let us verify that.

Note that the expected utility of citizen i is

$$E\,u_i((0,1),(0,1),(0,1);\langle 1\rangle) = \frac{1}{3}(a-z-1)+\frac{2}{3}a = \frac{1}{12},$$

and the expected utility of the governor is

$$Eu_G((0,1),(0,1),(0,1);\langle 1\rangle) = a = \frac{3}{4}.$$

For the strategy profile $((0,1),(0,1),(0,1);\langle 1\rangle)$ to be a Nash equilibrium, it should be mutual best responses for citizens and the governor to play the strategies prescribed in this profile. The only possible deviation for the governor is to embezzle 1 unit, i.e. play strategy $g = \langle 0\rangle$, and her expected utility in this case is

$$Eu_G((0,1),(0,1),(0,1);\langle 0\rangle) = 1-3b = -\frac{1}{2} < Eu_G((0,1),(0,1),(0,1);\langle 1\rangle).$$

The best possible deviation for citizen $i = 1$ is to pay the tax, and the corresponding expected utility is

$$Eu_1((1,1),(0,1),(0,1);\langle 1\rangle) = \frac{1}{3}(a-1)+\frac{2}{3}(a-1) = -\frac{1}{4} < Eu_1((0,1),(0,1),(0,1);\langle 1\rangle).$$

Thus, given our parameter values, the strategy profile $((0,1),(0,1),(0,1);\langle 1\rangle)$ is a Nash equilibrium. We generalize this result in subsection 1.3.3.

1.3.2 Efficient Public Good Provision

In the previous subsection, we had an *efficient public good provision* example where all three citizens pay taxes and expect three units of public goods from the governor, and the governor redistributes three units in the equilibrium. Our next result generalizes this example and provides conditions for the efficient public good provision.

THEOREM 1.1. *If the public good provision is efficient,*

$$an \geq 1,$$

and the punishment for embezzlement is high enough,

$$b \geq 1-a,$$

then there exists an efficient public good provision equilibrium where all citizens *pay taxes and expect $\tau = n$ units of public goods from the governor, and the governor redistributes g units using the following cutoff strategy:*

$$g = \langle n \rangle = \begin{cases} 0, & if X < n, \\ n, & if X = n. \end{cases}$$

Proof of Theorem 1.1. Consider a strategy profile $((1,n),...,(1,n);\langle n \rangle)$, where each citizen pays tax and expects n units of public good, and the Governor redistributes n units of public good, whenever possible. Thus, the expected utility of citizen i is

$$E u_i((1,n),...,(1,n);\langle n \rangle) = -1 + an,$$

and the expected utility of the Governor is

$$E u_G((1,n),...,(1,n);\langle n \rangle) = na.$$

For the strategy profile $((1,n),...,(1,n);\langle n \rangle)$ to be a Nash equilibrium, it should be a mutual best response for the players to play the strategy prescribed in the profile. Below we consider the best possible deviations for the Governor and citizens.

The best possible deviation for the Governor is to embezzle everything, $\langle 0 \rangle$, i.e. provide 0 units of public goods. In this case, the expected payoff for the Governor is:

$$E u_G((1,n),...,(1,n);\langle 0 \rangle) = n - nb.$$

In the equilibrium, it has to be

$$E u_G((1,n),...,(1,n);\langle n \rangle) \geq E u_G((1,n),...,(1,n);\langle 0 \rangle),$$

or

$$b \geq 1 - a. \tag{1.6}$$

The best possible deviation for citizen 1 is to evade the tax, $(0, n)$, which leads to the following expected utility for him

$$Eu_1((0,n),(1,n),...,(1,n);\langle n\rangle) = \frac{k}{n}(-1-z+na). \tag{1.7}$$

Note that when citizen 1 evades the tax and is not audited, Governor does not have enough public funds to provide n units of the public good and therefore embezzles all public funds.

In the equilibrium, it has to be

$$Eu_1((1,n),...,(1,n);\langle n\rangle) \geq Eu_1((0,n),(1,n),...,(1,n);\langle n\rangle),$$
$$z \geq \frac{(n-k)(1-an)}{k}.$$

Since the efficiency condition requires $an \geq 1$, the last inequality holds for any $z \geq 0$. Therefore, (1.6) gives us the condition for the efficient PG provision. □

The public good literature has long been looking for the efficient public good provision mechanisms. The most tractable solution is, probably, the public good provision with punishments. See for example Fehr and Gächter (2000, 2002). Theorem 1 demonstrates that the efficient public good provision can be achieved with a corrupt governor and without punishment for tax evasion if each citizen is pivotal in the following sense. Each citizen pays taxes and expects provision of all n units from the governor. If the governor does not provide exactly n units, then each citizen punishes her. The punishment is severe and the governor prefers to avoid it. This means that the governor will only consider two options: either provide all n units of public goods or embezzle the whole public fund. Therefore, each citizen is pivotal for the efficient public good provision: he expects that his deviation (tax evasion) leads to no public good provision (most likely, unless he is audited). The governor – the institution – executes the punishment and the reward here. Hence, surprisingly, we do not need to impose any punishment for the individual tax evasion. It is interesting to emphasize that the governor is corrupt and tries to embezzle public funds in the "right" situation, but, even in this case, she does not want to embezzle funds in the equilibrium.

Our finding has a similar flavor to that of Gallice and Monzón (2019), who consider a one-shot sequential public goods game with position uncertainty and with partial history of immediate predecessors. They find that there is an equilibrium where everyone contributes without the need of punishment.

1.3.3 Tax Evasion

In the example, we have already seen a *tax evasion* equilibrium where all three citizens evade taxes and expect the governor to redistribute just one unit of the public fund, which the governor always obliges. We generalize this result in the next theorem.

THEOREM 1.2. *If the punishment for tax evasion is relatively small*

$$z \leq \frac{(n-k)}{k},$$

and the punishment for embezzlement is high enough

$$b \geq \frac{k}{n}(1-a),$$

there exists a tax evasion equilibrium, where all citizens evade taxes and expect $\tau = k$ *units of public good, and the governor always provides exactly* $g = k$ *units.*

Proof of Theorem 1.2. Consider a strategy profile $((0,k),(0,k),\ldots,(0,k);\langle k\rangle)$, where each citizen i evades the tax and expects k units of public goods, and the Governor redistributes k units of public goods by means of a cut-off strategy, $\langle k\rangle$. Thus, the expected utility of citizen i is

$$Eu_i((0,k),(0,k),\ldots,(0,k);\langle k\rangle) = \frac{k}{n}(-1-z+ka) + \left(1-\frac{k}{n}\right)(ka),$$

and the expected utility of the Governor is given by

$$Eu_G((0,k),(0,k),\ldots,(0,k);\langle k\rangle) = ka.$$

For the strategy profile $((0,k),(0,k),...,(0,k);\langle k\rangle)$ to be an equilibrium, it should be a mutual best response for the players to play the strategy prescribed in the profile. Below we consider the best possible deviations for the Governor and citizens.

The best possible deviation for the Governor is to embezzle everything, i.e. provide zero units of public goods. The expected payoff for the Governor in this case is

$$Eu_G((0,k),(0,k),...,(0,k);\langle 0\rangle) = k - nb.$$

In the equilibrium, it must be

$$Eu_G((0,k),(0,k),...,(0,k);\langle k\rangle) \geq EU_G((0,k),(0,k),...,(0,k);\langle 0\rangle),$$

or

$$b \geq \frac{k(1-a)}{n}. \tag{1.8}$$

The best possible deviation for citizen 1 is to pay the tax, $(1,k)$. The expected utility for citizen 1 in this case is

$$Eu_1((1,k),(0,k),...,(0,k);\langle k\rangle) = -1 + ak \tag{1.9}$$

In the equilibrium, it has to be

$$Eu_1((0,k),(0,k),...,(0,k);\langle k\rangle) \geq Eu_1((1,k),(0,k),...,(0,k);\langle k\rangle), or$$

$$z \leq \frac{(n-k)}{k}. \tag{1.10}$$

Thus, (1.8) and (1.10) provide conditions for the tax evasion equilibrium. □

There are several important points to note from Theorem 2. First, if the punishment for tax evasion is relatively small, then all citizens can evade taxes and expect the minimal level of public good provision, k units, from the governor, who in turn does not have any incentives to produce more than k units of public goods. These citizens' expectations are self-enforced in the equilibrium.

Second, punishment conditions for the tax evasion equilibrium depend on the population size, n, and the number of audited citizens, k. If the population size, n, and the punishment for tax evasion, z, are fixed, then increasing the audit level, k, makes it more difficult to sustain the equilibrium. Similarly, if the audit level, k, and the punishment for tax evasion, z, are fixed, then increasing the population size, n, makes it easier to sustain the tax evasion equilibrium.

Finally, a tax audit experiment conducted in Denmark (Kleven et al., 2011) finds that for self-reported income, the empirical results are consistent with our theoretical prediction: tax evasion is widespread and is negatively related to an increase in penalties.

1.3.4 Symmetric Mixed Strategy Equilibrium

So far we have considered two extreme cases: in the efficient equilibrium, all citizens pay taxes and the governor redistributes the entire public fund (Theorem 1); in the tax evasion equilibrium, all citizens evade taxes and the governor redistributes the minimal amount (Theorem 2). The following result generalizes Theorems 1 and 2.

THEOREM 1.3. *For any citizens' expectations, $\tau \in \{k, k+1, ..., n\}$, there exists a symmetric mixed strategy equilibrium $((p,\tau), ...(p,\tau); \langle\tau\rangle)$, where*

- *all citizens pay taxes with probability $p = \frac{\tau-k}{n-k}$ and expect τ units of public goods;*
- *the governor uses the cutoff strategy, $\langle\tau\rangle$, for public good provision, where*

$$\langle\tau\rangle = \begin{cases} 0, & \text{if } X < \tau, \\ \tau, & \text{if } X \geq \tau. \end{cases}$$

In the equilibrium, the penalty for the tax evasion, $z^* = z(p, a)$ is uniquely determined, and the penalty for the embezzlement, $b \geq b^*$, has to be above the threshold level, $b^* = b(\tau, a)$.

Proof of Theorem 1.3. Consider a mixed strategy $\sigma_{-i} = (p, \tau)$ where citizens $-i$ randomise between paying or evading taxes and expect τ units to be provided by the Governor, and let us assume that the Governor plays a cut-off strategy, $\langle \tau \rangle$, for public good provision, where

$$\langle \tau \rangle = \begin{cases} 0, & \text{if } X < \tau, \\ \tau, & \text{if } X \geq \tau. \end{cases}$$

The expected utility of citizen i when paying tax is given by:

$$\begin{aligned}
&E u_i((1,\tau), \sigma_{-i}; \langle \tau \rangle) \\
&= \frac{k}{n}\Bigg[\sum_{j=\tau-1}^{n-1} \binom{n-1}{j} p^j (1-p)^{n-1-j} (-1+\tau a) \\
&+ \sum_{j=\tau-k}^{\tau-2} \binom{n-1}{j} p^j (1-p)^{n-1-j} \left(\sum_{k_s=\tau-1-j}^{k-1} \frac{\binom{j}{k-1-k_s}\binom{n-1-j}{k_s}}{\binom{n-1}{k-1}} \right)(-1+\tau a) \\
&+ \sum_{j=\tau-k}^{\tau-2} \binom{n-1}{j} p^j (1-p)^{n-1-j} \left(\sum_{k_s=0}^{\tau-2-j} \frac{\binom{j}{k-1-k_s}\binom{n-1-j}{k_s}}{\binom{n-1}{k-1}} \right)(-1) \\
&+ \sum_{j=0}^{\tau-k-1} \binom{n-1}{j} p^j (1-p)^{n-1-j} (-1) \Bigg] \\
&+ (1-\frac{k}{n})\Bigg[\sum_{j=\tau-1}^{n-1} \binom{n-1}{j} p^j (1-p)^{n-1-j} (-1+\tau a) \\
&+ \sum_{j=\tau-k-1}^{\tau-2} \binom{n-1}{j} p^j (1-p)^{n-1-j} \left(\sum_{k_s=\tau-1-j}^{k} \frac{\binom{j}{k-k_s}\binom{n-1-j}{k_s}}{\binom{n-1}{k}} \right)(-1+\tau a) \\
&+ \sum_{j=\tau-k-1}^{\tau-2} \binom{n-1}{j} p^j (1-p)^{n-1-j} \left(\sum_{k_s=0}^{\tau-2-j} \frac{\binom{j}{k-k_s}\binom{n-1-j}{k_s}}{\binom{n-1}{k}} \right)(-1) \\
&+ \sum_{j=0}^{\tau-k-2} \binom{n-1}{j} p^j (1-p)^{n-1-j} (-1) \Bigg]. \qquad (1.11)
\end{aligned}$$

Similarly, the expected utility of citizen i by evading tax is given by:

$$
\begin{aligned}
&E u_i((0,\tau),\sigma_{-i};\langle\tau\rangle)\\
&=\frac{k}{n}\Bigg[\sum_{j=\tau-1}^{n-1}\binom{n-1}{j}p^j(1-p)^{n-1-j}(-1+\tau a-z)\\
&+\sum_{j=\tau-k}^{\tau-2}\binom{n-1}{j}p^j(1-p)^{n-1-j}\Bigg(\sum_{k_s=\tau-1-j}^{k-1}\frac{\binom{j}{k-1-k_s}\binom{n-1-j}{k_s}}{\binom{n-1}{k-1}}\Bigg)(-1+\tau a-z)\\
&+\sum_{j=\tau-k}^{\tau-2}\binom{n-1}{j}p^j(1-p)^{n-1-j}\Bigg(\sum_{k_s=0}^{\tau-2-j}\frac{\binom{j}{k-1-k_s}\binom{n-1-j}{k_s}}{\binom{n-1}{k-1}}\Bigg)(-1-z)\\
&+\sum_{j=0}^{\tau-k-1}\binom{n-1}{j}p^j(1-p)^{n-1-j}(-1-z)\Bigg]\\
&+(1-\frac{k}{n})\Bigg[\sum_{j=\tau}^{n-1}\binom{n-1}{j}p^j(1-p)^{n-1-j}(\tau a)\\
&+\sum_{j=\tau-k}^{\tau-1}\binom{n-1}{j}p^j(1-p)^{n-1-j}\Bigg(\sum_{k_s=\tau-j}^{k}\frac{\binom{j}{k-k_s}\binom{n-1-j}{k_s}}{\binom{n-1}{k}}\Bigg)(\tau a)\\
&+\sum_{j=\tau-k}^{\tau-1}\binom{n-1}{j}p^j(1-p)^{n-1-j}\Bigg(\sum_{k_s=0}^{\tau-1-j}\frac{\binom{j}{k-k_s}\binom{n-1-j}{k_s}}{\binom{n-1}{k}}\Bigg)(0)\\
&+\sum_{j=0}^{\tau-k-1}\binom{n-1}{j}p^j(1-p)^{n-1-j}(0)\Bigg].
\end{aligned}
\tag{1.12}
$$

By re-writing the sums, using distributive law, inside the second square brackets of (1.11), we get

$$
\begin{aligned}
&E u_i((1,\tau),\sigma_{-i};\langle\tau\rangle)\\
&=\frac{k}{n}\Bigg[\sum_{j=\tau-1}^{n-1}\binom{n-1}{j}p^j(1-p)^{n-1-j}(-1+\tau a)\\
&+\sum_{j=\tau-k}^{\tau-2}\binom{n-1}{j}p^j(1-p)^{n-1-j}\Bigg(\sum_{k_s=\tau-1-j}^{k-1}\frac{\binom{j}{k-1-k_s}\binom{n-1-j}{k_s}}{\binom{n-1}{k-1}}\Bigg)(-1+\tau a)\\
&+\sum_{j=\tau-k}^{\tau-2}\binom{n-1}{j}p^j(1-p)^{n-1-j}\Bigg(\sum_{k_s=0}^{\tau-2-j}\frac{\binom{j}{k-1-k_s}\binom{n-1-j}{k_s}}{\binom{n-1}{k-1}}\Bigg)(-1)\\
&+\sum_{j=0}^{\tau-k-1}\binom{n-1}{j}p^j(1-p)^{n-1-j}(-1)\Bigg]\\
&+(1-\frac{k}{n})\Bigg[\sum_{j=\tau-1}^{n-1}\binom{n-1}{j}p^j(1-p)^{n-1-j}(-1)\\
&+\sum_{j=\tau-1}^{n-1}\binom{n-1}{j}p^j(1-p)^{n-1-j}(\tau a)\\
&+\sum_{j=\tau-k-1}^{\tau-2}\binom{n-1}{j}p^j(1-p)^{n-1-j}\Bigg(\sum_{k_s=\tau-1-j}^{k}\frac{\binom{j}{k-k_s}\binom{n-1-j}{k_s}}{\binom{n-1}{k}}\Bigg)(-1)\\
&+\sum_{j=\tau-k-1}^{\tau-2}\binom{n-1}{j}p^j(1-p)^{n-1-j}\Bigg(\sum_{k_s=\tau-1-j}^{k}\frac{\binom{j}{k-k_s}\binom{n-1-j}{k_s}}{\binom{n-1}{k}}\Bigg)(\tau a)\\
&+\sum_{j=\tau-k-1}^{\tau-2}\binom{n-1}{j}p^j(1-p)^{n-1-j}\Bigg(\sum_{k_s=0}^{\tau-2-j}\frac{\binom{j}{k-k_s}\binom{n-1-j}{k_s}}{\binom{n-1}{k}}\Bigg)(-1)\\
&+\sum_{j=0}^{\tau-k-2}\binom{n-1}{j}p^j(1-p)^{n-1-j}(-1)\Bigg]
\end{aligned}
\tag{1.13}
$$

Further simplifying (1.13) gives us,

$$
\begin{aligned}
Eu_i((1,\tau),\sigma_{-i};\langle\tau\rangle) = \frac{k}{n}\Bigg[& \sum_{j=\tau-1}^{n-1}\binom{n-1}{j}p^j(1-p)^{n-1-j}(-1+\tau a) \\
& + \sum_{j=\tau-k}^{\tau-2}\binom{n-1}{j}p^j(1-p)^{n-1-j}\Bigg(\sum_{k_s=\tau-1-j}^{k-1}\frac{\binom{j}{k-1-k_s}\binom{n-1-j}{k_s}}{\binom{n-1}{k-1}}\Bigg)(-1+\tau a) \\
& + \sum_{j=\tau-k}^{\tau-2}\binom{n-1}{j}p^j(1-p)^{n-1-j}\Bigg(\sum_{k_s=0}^{\tau-2-j}\frac{\binom{j}{k-1-k_s}\binom{n-1-j}{k_s}}{\binom{n-1}{k-1}}\Bigg)(-1) \\
& + \sum_{j=0}^{\tau-k-1}\binom{n-1}{j}p^j(1-p)^{n-1-j}(-1)\Bigg] \\
& + (1-\frac{k}{n})\Bigg[(-1) + \sum_{j=\tau-1}^{n-1}\binom{n-1}{j}p^j(1-p)^{n-1-j}(\tau a) \\
& + \sum_{j=\tau-k-1}^{\tau-2}\binom{n-1}{j}p^j(1-p)^{n-1-j}\Bigg(\sum_{k_s=\tau-1-j}^{k}\frac{\binom{j}{k-k_s}\binom{n-1-j}{k_s}}{\binom{n-1}{k}}\Bigg)(\tau a)\Bigg]
\end{aligned} \tag{1.14}
$$

Citizen i will be indifferent if $Eu_i((1,\tau),\sigma_{-i},\langle\tau\rangle) = Eu_i(0,\tau);\sigma_{-i};\langle\tau\rangle)$. Therefore, equating (1.12) and (1.14) and simplifying we get,

$$
\begin{aligned}
\frac{k}{n}(-z) = (1-\frac{k}{n})\Bigg[& (-1) + \sum_{j=\tau-1}^{n-1}\binom{n-1}{j}p^j(1-p)^{n-1-j}(\tau a) \\
& + \sum_{j=\tau-k-1}^{\tau-2}\binom{n-1}{j}p^j(1-p)^{n-1-j}\Bigg(\sum_{k_s=\tau-1-j}^{k}\frac{\binom{j}{k-k_s}\binom{n-1-j}{k_s}}{\binom{n-1}{k}}\Bigg)(\tau a) \\
& - \sum_{j=\tau}^{n-1}\binom{n-1}{j}p^j(1-p)^{n-1-j}(\tau a) \\
& - \sum_{j=\tau-k}^{\tau-1}\binom{n-1}{j}p^j(1-p)^{n-1-j}\Bigg(\sum_{k_s=\tau-j}^{k}\frac{\binom{j}{k-k_s}\binom{n-1-j}{k_s}}{\binom{n-1}{k}}\Bigg)(\tau a)\Bigg] \\
= (1-\frac{k}{n})\Bigg[& (-1) + \binom{n-1}{\tau-1}p^{\tau-1}(1-p)^{n-\tau}(\tau a) \\
& + \sum_{j=\tau-k-1}^{\tau-2}\binom{n-1}{j}p^j(1-p)^{n-1-j}\Bigg(\sum_{k_s=\tau-1-j}^{k}\frac{\binom{j}{k-k_s}\binom{n-1-j}{k_s}}{\binom{n-1}{k}}\Bigg)(\tau a) \\
& - \sum_{j=\tau-k}^{\tau-1}\binom{n-1}{j}p^j(1-p)^{n-1-j}\Bigg(\sum_{k_s=\tau-j}^{k}\frac{\binom{j}{k-k_s}\binom{n-1-j}{k_s}}{\binom{n-1}{k}}\Bigg)(\tau a)\Bigg].
\end{aligned}
$$

Solving for z we get,

$$\begin{aligned} z = \left(\frac{k-n}{k}\right)\Bigg[(-1) + \binom{n-1}{\tau-1} p^{\tau-1}(1-p)^{n-\tau}(\tau a) \\ + \sum_{j=\tau-k-1}^{\tau-2} \binom{n-1}{j} p^{j}(1-p)^{n-1-j}\left(\sum_{k_s=\tau-1-j}^{k} \frac{\binom{j}{k-k_s}\binom{n-1-j}{k_s}}{\binom{n-1}{k}}\right)(\tau a) \\ - \sum_{j=\tau-k}^{\tau-1} \binom{n-1}{j} p^{j}(1-p)^{n-1-j}\left(\sum_{k_s=\tau-j}^{k} \frac{\binom{j}{k-k_s}\binom{n-1-j}{k_s}}{\binom{n-1}{k}}\right)(\tau a)\Bigg] \end{aligned} \tag{1.15}$$

Rewriting equation (1.15):

$$z = \left(\frac{n-k}{k}\right)\Big[(1) - A\tau a - B\tau a + C\tau a\Big],$$

where,

$$\begin{aligned} A &= \binom{n-1}{\tau-1} p^{\tau-1}(1-p)^{n-\tau} \\ B &= \sum_{j=\tau-k-1}^{\tau-2} \binom{n-1}{j} p^{j}(1-p)^{n-1-j}\left(\sum_{k_s=\tau-1-j}^{k} \frac{\binom{j}{k-k_s}\binom{n-1-j}{k_s}}{\binom{n-1}{k}}\right) \\ C &= \sum_{j=\tau-k}^{\tau-1} \binom{n-1}{j} p^{j}(1-p)^{n-1-j}\left(\sum_{k_s=\tau-j}^{k} \frac{\binom{j}{k-k_s}\binom{n-1-j}{k_s}}{\binom{n-1}{k}}\right) \end{aligned}$$

For z to be non-negative we need:

$$\begin{aligned} 1 - A\tau a - B\tau a + C\tau a &\geq 0 \\ a &\leq \frac{1}{\tau\big(A + B - C\big)} \end{aligned} \tag{1.16}$$

From Lemma 1 we have,

$$\begin{aligned} k + p(n-k) &= \tau \\ p &= \frac{\tau - k}{n-k} \end{aligned} \tag{1.17}$$

Fixing τ, k, n we have p uniquely determined. Plugging this p in equation (1.15) we get a unique value of z.

Assuming the citizens pay taxes with probability p, for the profile $(\sigma;\sigma_{-i};\langle\tau\rangle)$ to be a symmetric MSNE, we want the Governor's best response to be his cut-off strategy, $\langle\tau\rangle$, i.e.,

$$E\,u_G(\sigma_i,\sigma_{-i};\langle\tau\rangle) \geq E\,u_G(\sigma_i,\sigma_{-i};0) \tag{1.18}$$

where the left hand side of the inequality (1.18) is

$$\begin{aligned}
&E\,u_G(\sigma_i;\sigma_{-i};\langle\tau\rangle)\\
&=\sum_{j=\tau}^{n}\binom{n}{j}p^j(1-p)^{n-j}\Bigg(\sum_{k_s=0}^{k}\frac{\binom{j}{k-k_s}\binom{n-j}{k_s}}{\binom{n}{k}}(\tau a+j+k_s-\tau)\Bigg)\\
&+\sum_{j=0}^{\tau-1}\binom{n}{j}p^j(1-p)^{n-j}\Bigg(\sum_{k_s=\tau-j}^{k}\frac{\binom{j}{k-k_s}\binom{n-j}{k_s}}{\binom{n}{k}}(\tau a+j+k_s-\tau)\Bigg)\\
&+\sum_{j=0}^{\tau-1}\binom{n}{j}p^j(1-p)^{n-j}\Bigg(\sum_{k_s=0}^{\tau-j-1}\frac{\binom{j}{k-k_s}\binom{n-j}{k_s}}{\binom{n}{k}}(j+k_s-nb)\Bigg)
\end{aligned} \tag{1.19}$$

Using absorption identity on the second expression and simplifying the first expression of (1.19) we get,

$$\begin{aligned}
&E\,u_G(\sigma_i;\sigma_{-i};\langle\tau\rangle)\\
&=\sum_{j=\tau}^{n}\binom{n}{j}p^j(1-p)^{n-j}(\tau a-\tau+j+k-\frac{jk}{n})\\
&+\sum_{j=0}^{\tau-1}\binom{n}{j}p^j(1-p)^{n-j}\Bigg(\sum_{k_s=\tau-j}^{k}\frac{\binom{j}{k-k_s}\binom{n-j}{k_s}}{\binom{n}{k}}(\tau a-\tau+j)+\sum_{k_s=\tau-j}^{k}\frac{\binom{j}{k-k_s}\binom{n-j}{k_s}}{\binom{n}{k}}(k_s)\Bigg)\\
&+\sum_{j=0}^{\tau-1}\binom{n}{j}p^j(1-p)^{n-j}\Bigg(\sum_{k_s=0}^{\tau-j-1}\frac{\binom{j}{k-k_s}\binom{n-j}{k_s}}{\binom{n}{k}}(j-nb)+\sum_{k_s=0}^{\tau-j-1}\frac{\binom{j}{k-k_s}\binom{n-j-1}{k_s-1}}{\binom{n}{k}}(n-j)\Bigg)
\end{aligned} \tag{1.20}$$

Using absorption identity on the second expression of (1.19) we get,

$$
\begin{aligned}
&Eu_G(\sigma_i;\sigma_{-i};\langle\tau\rangle)\\
&=\sum_{j=\tau}^{n}\binom{n}{j}p^j(1-p)^{n-j}(\tau a-\tau+j+k-\frac{jk}{n})\\
&+\sum_{j=0}^{\tau-1}\binom{n}{j}p^j(1-p)^{n-j}\Bigg(\sum_{k_s=\tau-j}^{k}\frac{\binom{j}{k-k_s}\binom{n-j}{k_s}}{\binom{n}{k}}(\tau a-\tau+j)+\sum_{k_s=\tau-j}^{k}\frac{\binom{j}{k-k_s}\binom{n-j-1}{k_s-1}}{\binom{n}{k}}(n-j)\Bigg)\\
&+\sum_{j=0}^{\tau-1}\binom{n}{j}p^j(1-p)^{n-j}\Bigg(\sum_{k_s=0}^{\tau-j-1}\frac{\binom{j}{k-k_s}\binom{n-j}{k_s}}{\binom{n}{k}}(j-nb)\sum_{k_s=1}^{\tau-j-1}\frac{\binom{j}{k-k_s}\binom{n-j-1}{k_s-1}}{\binom{n}{k}}(n-j)\Bigg) \qquad (1.21)
\end{aligned}
$$

Manipulating the second and the third expression of (1.21) we get

$$
\begin{aligned}
&Eu_G(\sigma_i,\sigma_{-i};\langle\tau\rangle)\\
&=\sum_{j=\tau}^{n}\binom{n}{j}p^j(1-p)^{n-j}(\tau a-\tau a+j+k-\frac{jk}{n})\\
&+\sum_{j=0}^{\tau-1}\binom{n}{j}p^j(1-p)^{n-j}\Bigg(\sum_{k_s=\tau-j}^{k}\frac{\binom{j}{k-k_s}\binom{n-j}{k_s}}{\binom{n}{k}}(\tau a-\tau)+\sum_{k_s=0}^{\tau-j-1}\frac{\binom{j}{k-k_s}\binom{n-j}{k_s}}{\binom{n}{k}}(-nb)\\
&+\sum_{k_s=1}^{k}\frac{\binom{j}{k-k_s}\binom{n-j-1}{k_s-1}}{\binom{n}{k}}(n-j)\Bigg) \qquad (1.22)
\end{aligned}
$$

Next we apply Vandermonde's identity on the last expression of (1.22)

$$
\begin{aligned}
&Eu_G(\sigma_i,\sigma_{-i};\langle\tau\rangle)\\
&=\sum_{j=\tau}^{n}\binom{n}{j}p^j(1-p)^{n-j}(\tau a-\tau+j+k-\frac{jk}{n})\\
&+\sum_{j=0}^{\tau-1}\binom{n}{j}p^j(1-p)^{n-j}\Bigg(\sum_{k_s=\tau-j}^{k}\frac{\binom{j}{k-k_s}\binom{n-j}{k_s}}{\binom{n}{k}}(\tau a-\tau)+\sum_{k_s=0}^{\tau-j-1}\frac{\binom{j}{k-k_s}\binom{n-j}{k_s}}{\binom{n}{k}}(-nb)+(j+k-\frac{jk}{n})\Bigg)\\
&Eu_G(\sigma_i,\sigma_{-i};\langle\tau\rangle)\\
&=k+(n-k)p+\sum_{j=\tau}^{n}\binom{n}{j}p^j(1-p)^{n-j}(\tau a-\tau)\\
&+\sum_{j=0}^{\tau-1}\binom{n}{j}p^j(1-p)^{n-j}\Bigg(\sum_{k_s=\tau-j}^{k}\frac{\binom{j}{k-k_s}\binom{n-j}{k_s}}{\binom{n}{k}}(\tau a-\tau)+\sum_{k_s=0}^{\tau-j-1}\frac{\binom{j}{k-k_s}\binom{n-j}{k_s}}{\binom{n}{k}}(-nb)\Bigg) \qquad (1.23)
\end{aligned}
$$

The right had side of the inequality (1.18) is

$$E\,u_G(\sigma_i,\sigma_{-i};0)=k+p(n-k)-nb \tag{1.24}$$

The proof for (1.24) is analogous to the proof of Lemma 1.

Using expressions (1.23) and (1.24) in (1.18) we have

$$\begin{aligned}
&k+(n-k)p+\sum_{j=\tau}^{n}\binom{n}{j}p^j(1-p)^{n-j}(\tau a-\tau)\\
&+\sum_{j=0}^{\tau-1}\binom{n}{j}p^j(1-p)^{n-j}\left(\sum_{k_s=\tau-j}^{k}\frac{\binom{j}{k-k_s}\binom{n-j}{k_s}}{\binom{n}{k}}(\tau a-\tau)+\sum_{k_s=0}^{\tau-j-1}\frac{\binom{j}{k-k_s}\binom{n-j}{k_s}}{\binom{n}{k}}(-nb)\right)\\
&\geq k+p(n-k)-nb
\end{aligned}\tag{1.25}$$

simplifying inequality (1.25)

$$\begin{aligned}
&\sum_{j=\tau}^{n}\binom{n}{j}p^j(1-p)^{n-j}(\tau-\tau a)\\
&+\sum_{j=0}^{\tau-1}\binom{n}{j}p^j(1-p)^{n-j}\left(\sum_{k_s=\tau-j}^{k}\frac{\binom{j}{k-k_s}\binom{n-j}{k_s}}{\binom{n}{k}}(\tau-\tau a)+\sum_{k_s=0}^{\tau-j-1}\frac{\binom{j}{k-k_s}\binom{n-j}{k_s}}{\binom{n}{k}}(nb)\right)\leq nb
\end{aligned}$$

and then solving for b

$$b\geq\frac{(\tau-\tau a)(D+E)}{n(1-F)}$$

where

$$\begin{aligned}
D&=\sum_{j=\tau}^{n}\binom{n}{j}p^j(1-p)^{n-j}\\
E&=\sum_{j=0}^{\tau-1}\binom{n}{j}p^j(1-p)^{n-j}\left(\sum_{k_s=\tau-j}^{k}\frac{\binom{j}{k-k_s}\binom{n-j}{k_s}}{\binom{n}{k}}\right)\\
F&=\sum_{j=0}^{\tau-1}\binom{n}{j}p^j(1-p)^{n-j}\left(\sum_{k_s=0}^{\tau-j-1}\frac{\binom{j}{k-k_s}\binom{n-j}{k_s}}{\binom{n}{k}}\right)
\end{aligned}$$

□

We provide an example for Theorem 3 in Appendix A.1. Theorem 3 gives conditions when it is optimal for the governor to match the citizens' expectations. For example, if the governor gets $\tau + m$ units in the public fund, then she will embezzle m units. At the same time, if she receives less than τ units, then the governor will embezzle everything.

Theorem 3 covers also two extreme cases. In the efficient equilibrium, citizens expect n units, i.e. $\tau = n$, and each citizen pays the tax with probability 1. In the tax evasion equilibrium, citizens expect k units, i.e. $\tau = k$, and every citizen evades the tax with probability 1. We get the following two corollaries from Theorem 3.

COROLLARY 1.1. *If $\tau = n$, then $p = 1$ and we have the efficient public good provision equilibrium.*

COROLLARY 1.2. *If $\tau = k$, then $p = 0$ and we have the tax evasion equilibrium.*

Theorem 3 shows the importance of citizens' expectations. Higher expectations lead to a higher level of tax payments and higher public good provision by the governor. In other words, higher citizens' expectations encourage a corrupt governor to embezzle less. At the same time, if the governor cannot meet the expectations, she embezzles everything. Citizens expect that and pay more taxes to give the governor a chance to produce more public goods. These driving equilibrium forces are self-fulfilled in the equilibrium.

1.4 Conclusion

We develop a model of tax evasion, corruption, and public good provision. In the model, citizens create public funds which the governor redistributes. The governor can embezzle some or all public funds. Here are some recent examples:

- Malaysia's ex-Prime Minister, Najib Razak, was arrested in 2018 for one of the world's biggest corruption scandals, where according to the US justice department, more than $4.5 billion funds were stolen from the 1Malaysia Development Berhad (1MDB). 1MDB is a Malaysian state fund set up in

2009 to promote development through foreign investments and partnerships, and then PM, Najib Razak, was the Chairman (Ellis-Peterson, 25 October 2018).

- A recent news article in Telegraph (Chazan, 5 June 2019) reports that financial prosecutors suspect that about £442,000 in public money may have been embezzled by Gerard Collomb, the Mayor of Lyon, France.
- Russian Legal Information Agency (RAPSI-News, 15 July 2019) reports that the Ex-Finance Minister of the Moscow Region, Alexey Kuznetsov, is charged with embezzling nearly $200 million.

In our model, we introduce social accountability as a part of an equilibrium strategy: citizens form their expectations about the public good provision. If these expectations are not met, then citizens punish the governor. A recent event illustrates this punishment: more than 12,000 Czechs gathered in Prague in a protest to demand the resignation of Prime Minister Andrej Babis over alleged misuse of EU Funds (Tait, 4 June 2019). With social accountability, we show that each citizen is pivotal and it is indeed possible to achieve the efficient public good provision with the right level of expectations.

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Chapter 2

Tax Evasion, Embezzlement and Public Good Provision

2.1 Introduction

Tax evasion and public good provision are the two prominent factors affecting the income and expenditure side of a government budget. It is often seen that countries fall into the vicious circle of political corruption (such as embezzlement of public funds by government officials for private gain) and tax evasion (Litina & Palivos, 2016). Despite the obvious link between *tax evasion, embezzlement and public good provision*, there is scant research that connects these three different strands of literature[1]. In chapter 1, we provide a model that connects the three strands of literature. This chapter complements the model in Chapter 1, by relaxing the assumption of symmetric strategies and considering all possible strategies.

We consider a simple model with two citizens and a governor. First, the citizens decide whether to pay or evade taxes. Then, Nature (an independent tax agency like Internal Revenue Service in the USA) audits one of the citizens, at random, and in case of non-payment, the citizen is forced to pay the tax and an additional penalty. The total tax collected goes into a public fund. After the tax payment decisions have been made by the citizens, the governor has to decide how much of the fund to use to provide a public good. Finally, after the governor's decision, citizens express their opinion on whether the governor stole

[1] See Cowell and Gordon (1988) for a related study linking literature on tax evasion and public good provision.

public funds or not. It is important to note that the citizens face asymmetry in information regarding the total public funds, conditional on who is being audited. We present our model in the form of a four-stage sequential game. The asymmetric behaviour of the citizens brings us closer to a more realistic society, where citizens act differently based on their beliefs. One could consider these two citizens as representatives of two different sections of a society, with homogeneity within the members of each section.

Even with our very simple structure, the asymmetry in citizens' behaviour opens up a wide range of possibilities which we discuss using the four basic parameters of the model: a penalty parameter for the non-payment of taxes (z), a punishment parameter for the embezzlement of funds (b), a marginal per capita return from the public good (α), and a citizen penalty parameter for wrong claim (c). Indeed, it turns out that any situation (after elimination of the dominated strategies) can be a Nash equilibrium for the right choice of parameters z, b, α, and c. Given the simplicity of our model and the amplitude of this result, it is possible to explain what conditions will result in a particular setting. For instance, we can provide specific restrictions on the parameters which will result in a particular scenario being the equilibrium for the model. In order to select among different Nash equilibria, we assume that citizens care about their claim, or $c > 0$. This natural assumption allows us to refine our predictions and discuss three Nash equilibria of interest: tax evasion, embezzlement, and efficient public good provision. We see that the conditions on the parameters characterising these three equilibria are quite intuitive.

The outline of this chapter is as follows. Section 2.2 describes our model and the reduced extensive form of the game. Section 2.3 presents the analysis of the model that includes the main results, a discussion of these results, and possible connections of these results with the existing literature. We conclude in Section 2.4.

2.2 Model

We consider a four-stage extensive form game involving two citizens and a governor. The citizens need to decide whether or not to pay taxes, given that they may be audited and punished (in case of non payment). Nature selects one of the citizens at random to audit. The total tax collected goes into a public fund. After the tax payment decisions have been made by the citizens, the governor has to decide how much of the fund to use to provide a public good. Finally citizens voice their opinion about the governor decision. We formally describe the four-stage game now.

Stage 1

Nature randomly selects to audit one of the two citizens with equal probability. Formally, the state of nature is $\Theta \in \{C_1, C_2\}$ where $\Pr\{\Theta = C_1\} = \Pr\{\Theta = C_2\} = \frac{1}{2}$ and citizen Θ is audited.

Stage 2

The choice of nature is not known to the citizens and $I^1_{i=1,2}$ denotes the information sets of citizen i at this stage. $C_{i=1,2}$ has to decide whether to pay taxes, $t_i = 1$, or not, $t_i = 0$. We assume that the tax is 1 unit for each citizen and the total taxes go towards a public fund. Any non-payment implies tax evasion, i.e. 0 unit paid towards the public fund. After the citizens make their decisions, the information about the audit is revealed. If a non tax-paying citizen is audited, he will need to pay $1 + z$, where $z \geq 0$ is the sanction (penalty) parameter.

Stage 3

Governor G receives the total public fund X, given by:

$$X = \begin{cases} 2, & if \quad \{\Theta = C_i\} \,\&\, \{t_{j \neq i} = 1\}, \\ 1, & if \quad \{\Theta = C_i\} \,\&\, \{t_{j \neq i} = 0\}. \end{cases} \tag{2.1}$$

If both citizens C_1 and C_2 pay taxes, the governor G will have $X = 2$ units, and it doesn't matter which citizen is audited. In a situation when both citizens C_1 and C_2 evade taxes (i.e. non-payment of taxes), one of them is audited and will have to pay 1 unit (along with a sanction of z), implying a total contribution of $X = 1$ unit. If only one of the citizens evades taxes we have $X = 2$ units ($X = 1$ unit) when the tax-evading citizen is audited (tax-evading citizen is not audited).

Formally, the governor G has two information sets : $\mathscr{I}_G = \{I_G^1, I_G^2\}$, where

$$I_G^1 = \{X = 1\} \text{ and } I_G^2 = \{X = 2\} \tag{2.2}$$

After G receives the public fund X, he decides how much of the public good to provide. When $X = 2$, the action set for G is $\{L, H\}$, where L (Low) and H (High) represent 1 and 2 units, respectively, of the public good provided by G. When $X = 1$, the governor G can only provide 1 unit, L, of the public good. We assume that G benefits from the public good provision too. We define an embezzling G as the governor who peculates one unit of public good when $X = 2$.

Stage 4

In the final stage of the game, we model a proxy for voting by incorporating a guessing mechanism where the citizens, C_1 and C_2, are required to guess whether total fund, X, is high (h) or low (l). We assume that wrong guess is costly and each citizen wants to guess correctly. Depending on which citizen was audited in Stage 1, one of them has more information about the possible X; we explain this below.

- If G plays H (provides 2 units of public good), each citizen has the dominant (guess) action h.
- If G plays L (provides 1 unit of public good), each citizen $C_{i=1,2}$ has three information sets: I_i^2, I_i^3, I_i^4, where

  $$I_i^2 = \{(\Theta = C_i, t_{j\neq i} = 0, L), (\Theta = C_i, t_{j\neq i} = 1, L)\}, \tag{2.3}$$

  $$I_i^3 = \{(\Theta = C_{j\neq i}, t_i = 1, L)\}, \tag{2.4}$$

  and

  $$I_i^4 = \{(\Theta = C_{j\neq i}, t_i = 0, L)\}. \tag{2.5}$$

At I_i^2, citizen C_i is not sure about the total public fund X and C_i's action set is $\{l, h\}$. At I_i^3, citizen C_i knows $X = 2$ and his dominant action is h. Similarly at

I_i^4, citizen C_i knows $X = 1$ and his dominant action is l. For each citizen $C_{i=1,2}$, let g_i denote the guesses made by him:

$$g_i \in \{h, l\} \tag{2.6}$$

The guessing mechanism helps in representing a set-up where the citizens can punish (file a complaint, for example) against a governor who embezzles. The only situation this can happen is when $X = 2$ and the governor decides to provide 1 unit of the public good. Given that the governor embezzles, if the citizens correctly guess the total X, G's payoff will decrease by $b \geq 0$ for every correct guess, i.e. the governor loses confidence of his citizens. On the other hand, C_i's payoff will decrease by $c \geq 0$ for a wrong guess.

We consider α as the marginal per capita return (or MPCR) of the public good, with $\alpha > 0$. The game concludes after Stage 4.

The payoff of $C_{i=1,2}$ is a function of:

$$\left[\Theta \in \{C_1, C_2\}; t_1, t_2 \in \{0, 1\}; \{L, H\}; g_i \in \{h, l\}\right].$$

The payoff for G is a function of:

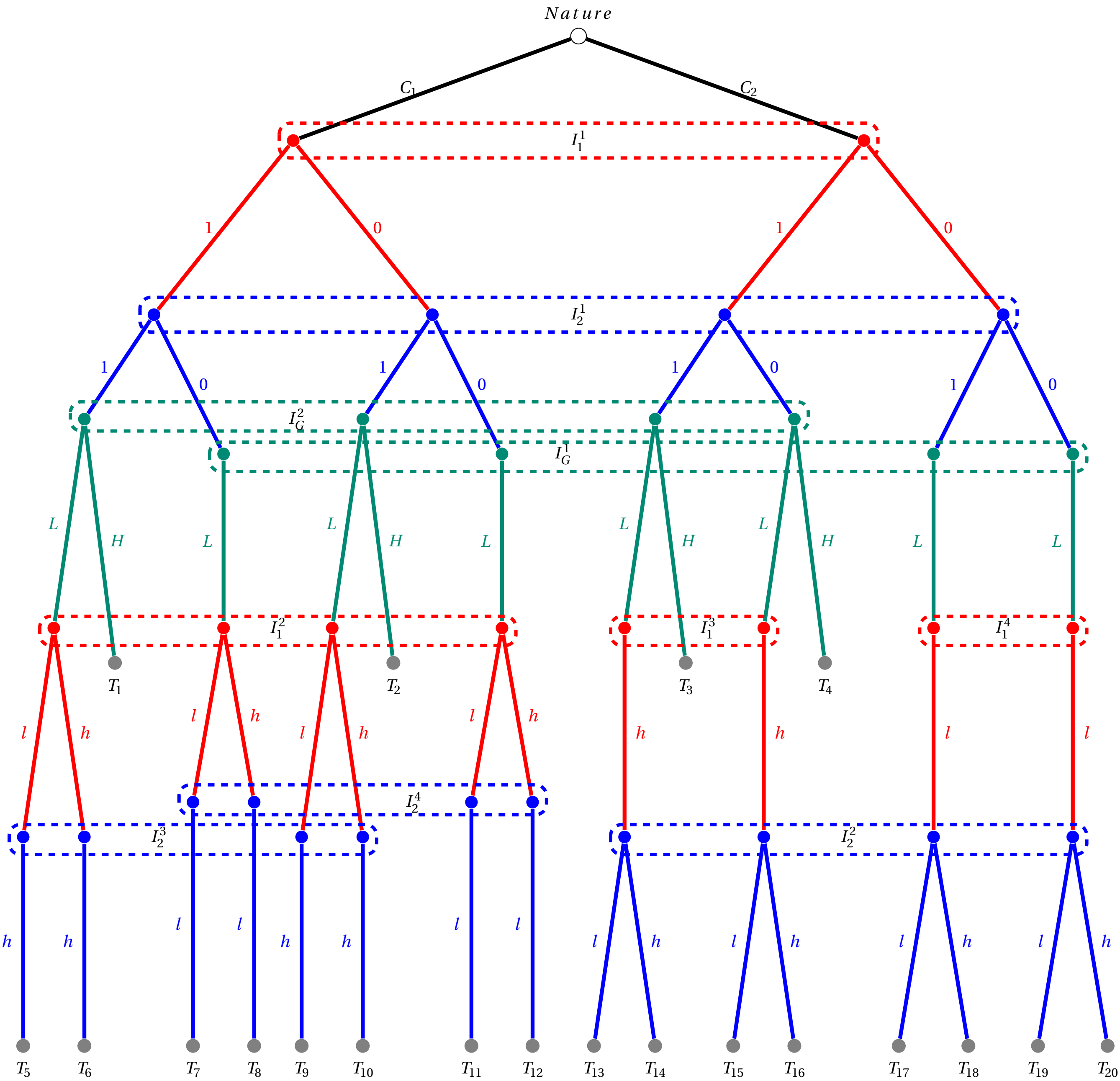
$$[\Theta \in \{C_1, C_2\}; t_1, t_2 \in \{0, 1\}; \{L, H\}; g_1, g_2 \in \{h, l\}].$$

Game Tree

We represent our extensive form game with a game tree. The nature starts the game by choosing which citizen C_1 or C_2 to audit (with probability $\frac{1}{2}$). C_1 and C_2 do not know who is being audited and they decide, simultaneously, whether to pay or evade taxes. The total taxes go towards a public fund (X). After citizens have made their moves, G receives X. G can not observe the actions of C_1 and C_2 from the previous stage and has two information sets: I_G^2 for $X = 2$ and I_G^1 for $X = 1$. At I_G^2 he has two actions, either provide 2 units (H) or provide 1 unit (L) of the public good; while at I_G^1 his only action is L. After G has made his decision, C_1 and C_2 will guess how much X was, which is the last stage of the game. When C_i is not sure about X he will be at information set I_i^2. At information set

I_i^3(similarly, I_i^4), C_i is sure that $X = 2$ ($X = 1$), and thus has a dominant action of h (l). This gives us the reduced form of the game tree with 20 terminal nodes and the corresponding payoffs being summarized in Table 2.1.

Figure 2.1: Reduced extensive form of the game



	Information sets	Color
C_1	$I_1^1, I_1^2, I_1^3, I_1^4$	red
C_2	$I_2^1, I_2^2, I_2^3, I_2^4$	blue
G	I_G^1, I_G^2	green

Table 2.1: Table of Payoffs

Terminal nodes	C_1	C_2	G
T_1	$-1+2\alpha$	$-1+2\alpha$	2α
T_2	$-1-z+2\alpha$	$-1+2\alpha$	2α
T_3	$-1+2\alpha$	$-1+2\alpha$	2α
T_4	$-1+2\alpha$	$-1-z+2\alpha$	2α
T_5	$-1+\alpha-c$	$-1+\alpha$	$1+\alpha-b$
T_6	$-1+\alpha$	$-1+\alpha$	$1+\alpha-2b$
T_7	$-1+\alpha$	α	α
T_8	$-1+\alpha-c$	α	α
T_9	$-1-z+\alpha-c$	$-1+\alpha$	$1+\alpha-b$
T_{10}	$-1-z+\alpha$	$-1+\alpha$	$1+\alpha-2b$
T_{11}	$-1-z+\alpha$	α	α
T_{12}	$-1-z+\alpha-c$	α	α
T_{13}	$-1+\alpha$	$-1+\alpha-c$	$1+\alpha-b$
T_{14}	$-1+\alpha$	$-1+\alpha$	$1+\alpha-2b$
T_{15}	$-1+\alpha$	$-1-z+\alpha-c$	$1+\alpha-b$
T_{16}	$-1+\alpha$	$-1-z+\alpha$	$1+\alpha-2b$
T_{17}	α	$-1+\alpha$	α
T_{18}	α	$-1+\alpha-c$	α
T_{19}	α	$-1-z+\alpha$	α
T_{20}	α	$-1-z+\alpha-c$	α

2.3 Analysis of the Model

A pure strategy for a citizen (or governor) specifies a complete plan of actions, i.e. an action for the citizen (or governor) at each information set. For each $i \in 1,2$, the pure strategy set for citizen C_i consists of the Cartesian product $\{1,0\} \times \{l,h\} \times \{l,h\} \times \{l,h\}$. Similarly, the pure strategy set for governor G is given by $\{L,H\} \times \{L\}$. Each citizen has 4 information sets with 2 actions at each information set. Therefore, each citizen has $2^4 = 16$ pure strategies. The pure strategy set of citizen $i \in 1,2$ is $S_i = \{1lll, 1llh, 1lhl, \ldots, 1hhh, 0lll, \ldots, 0hhh\}$.

At information sets I_i^3 and I_i^4, h and l are the dominant actions for citizen i. Thus, we eliminate dominated strategies and consider only a "reduced" strategy set (with some abuse of notation) for citizen i : $S_i' = \{1l, 1h, 0l, 0h\}$, where two actions in each strategy report choices at information sets $I_i^1$and I_i^2. The governor has only one action at information set I_G^1. Thus, with some abuse of notation, we denote the governor's strategy set as $S_G' = \{L, H\}$. The following reduced normal form game $\mathscr{B}$ (see Table 2.2) summarizes the expected payoffs[2] for all the possible outcomes of the game.

We are ready to present our first result now.

THEOREM 2.1. *For any strategy profile $s^* = (s_1, s_2, s_G)$, there exist parameters z, c, α, b such that s^* is a pure strategy Nash equilibrium, where $s_{i=1,2} \in \{(1l), (1h), (0l), (0h)\}$ and $s_G \in \{L, H\}$.*

Proof of Theorem 2.1. For any strategy profile to be a PSNE, strategies of players in the profile have to be mutual best responses. Consider the strategy profile $((1l), (1l), L)$. For C_1 (similarly, C_2), given that C_2 (C_1) plays $1l$ and L, respectively, $1l$ has to be the response of citizen C_1 (C_2). Given that C_1 and C_2 plays $1l$, L has to be the best response of G. That is, for $C_{i=1,2}$, we have the following:

$$E u_{C_i}(1l, 1l, L) \geq E u_{C_i}(1h, 1l, L)$$
$$-1 + \alpha - \frac{1}{2}c \geq -1 + \alpha$$
$$c \leq 0$$

[2]An example: A strategy profile such as $(1h, 0l, L)$ refers to citizen 1 playing $1h$, citizen 2 playing $0l$ and the governor G playing L. Given this, the expected payoffs are as follows:

$$E(u_{C_1}) = \frac{1}{2}(-1 + \alpha - c) + \frac{1}{2}(-1 + \alpha) = -1 + \alpha - \frac{1}{2}c$$

$$E(u_{C_2}) = \frac{1}{2}\alpha + \frac{1}{2}(-1 + \alpha - z - c) = -\frac{1}{2} + \alpha - \frac{1}{2}z - \frac{1}{2}c$$

$$E(u_G) = \frac{1}{2}\alpha + \frac{1}{2}(1 + \alpha - b) = \frac{1}{2} + \alpha - \frac{1}{2}b$$

$$
\begin{aligned}
Eu_{C_i}(1l,1l,L) &\geq Eu_{C_i}(0l,1l,L)\\
-1+\alpha-\frac{1}{2}c &\geq -\frac{1}{2}+\alpha-\frac{1}{2}z-\frac{1}{2}c\\
z &\geq 1
\end{aligned}
$$

$$
\begin{aligned}
Eu_{C_i}(1l,1l,L) &\geq Eu_{C_i}(0h,1l,L)\\
-1+\alpha-\frac{1}{2}c &\geq -\frac{1}{2}+\alpha-\frac{1}{2}z\\
z &\geq 1+c
\end{aligned}
$$

and for G, we have

$$
\begin{aligned}
Eu_G(1l,1l,L) &\geq Eu_G(1l,1l,H)\\
1-b+\alpha &\geq 2\alpha\\
b &\leq 1-\alpha
\end{aligned}
$$

From the inequalities above, we have $z \geq 1$, $c = 0$ and $b \leq 1-\alpha$ as the conditions for the strategy profile $((1l),(1l),L)$ to be a PSNE. Analogously, we can derive the conditions on parameters z, b, c, α required for the remaining 31 strategy profiles to be a PSNE for the reduced normal form game. In the interest of space and to avoid repetition, we do not include the proofs here in this chapter but a summary of the conditions have been provided in Table 2.3. □

We observe that any strategy profile in the reduced normal form game $\mathscr{B}$ can be a PSNE and Table 2.2 summarizes the corresponding conditions on the parameters z, c, b, α such that Theorem 1 holds true. Each cell in Table 2 provides the restrictions on the parameters such that the outcome corresponding to that particular cell (from Table 2.2) is a PSNE. For example, consider the outcome $((0h),(1h),H)$ in Table 2.2 where citizen 1 plays $0h$, citizen 2 plays $1h$ and governor chooses to play H. From Table 2.3, it is easy to see that when $c = 0$, $z = 1-\alpha$ and $b \geq \frac{1}{2}(1-\alpha)$, $((0h),(1h),H)$ is a PSNE of the game. Our model provides an extremely rich setting which helps us describe any possible situation using four simple parameters. We are not aware of another model which obtains a similar result, where any outcome can be generated (as a PSNE) by selecting a suitable set of parameters. Given the the amplitude of this result, it is possible to explain what conditions will result in a particular setting. For instance, we can provide specific restrictions on the parameters which will result in a particular scenario (such as the citizens evading taxes or the governor embezzling funds, etc.) to exist in a society.

It is important to note that in this model the citizens are asymmetric, and therefore Theorem 1 encompasses many possibilities (see Chapter 1 for some results in a symmetric game) We now want to restrict our discussion to some specific situations of economic interest and for the purpose of doing so we assume some restrictions on parameter c.

Table 2.2: Reduced normal form game

	L					H			
	$1l$	$1h$	$0l$	$0h$		$1l$	$1h$	$0l$	$0h$
$1l$	$-1+\alpha-\frac{1}{2}c$ $-1+\alpha-\frac{1}{2}c$ $1+\alpha-b$	$-1+\alpha-\frac{1}{2}c$ $-1+\alpha$ $1+\alpha-\frac{3}{2}b$	$-1+\alpha$ $-\frac{1}{2}-\frac{1}{2}z+\alpha-\frac{1}{2}c$ $\frac{1}{2}+\alpha-\frac{1}{2}b$	$-1+\alpha$ $-\frac{1}{2}-\frac{1}{2}z+\alpha$ $\frac{1}{2}+\alpha-b$	$1l$	$-1+2\alpha$ $-1+2\alpha$ 2α	$-1+2\alpha$ $-1+2\alpha$ 2α	$-1+\frac{3}{2}\alpha$ $-\frac{1}{2}-\frac{1}{2}z+\frac{3}{2}\alpha$ $\frac{3}{2}\alpha$	$-1+\frac{3}{2}\alpha$ $-\frac{1}{2}-\frac{1}{2}z+\frac{3}{2}\alpha$ $\frac{3}{2}\alpha$
$1h$	$-1+\alpha$ $-1+\alpha-\frac{1}{2}c$ $1+\alpha-\frac{3}{2}b$	$-1+\alpha$ $-1+\alpha$ $1+\alpha-2b$	$-1+\alpha-\frac{1}{2}c$ $-\frac{1}{2}-\frac{1}{2}z+\alpha-\frac{1}{2}c$ $\frac{1}{2}+\alpha-\frac{1}{2}b$	$-1+\alpha-\frac{1}{2}c$ $-\frac{1}{2}-\frac{1}{2}z+\alpha$ $\frac{1}{2}+\alpha-b$	$1h$	$-1+2\alpha$ $-1+2\alpha$ 2α	$-1+2\alpha$ $-1+2\alpha$ 2α	$-1+\frac{3}{2}\alpha-\frac{1}{2}c$ $-\frac{1}{2}-\frac{1}{2}z+\frac{3}{2}\alpha$ $\frac{3}{2}\alpha$	$-1+\frac{3}{2}\alpha-\frac{1}{2}c$ $-\frac{1}{2}-\frac{1}{2}z+\frac{3}{2}\alpha$ $\frac{3}{2}\alpha$
$0l$	$-\frac{1}{2}-\frac{1}{2}z+\alpha-\frac{1}{2}c$ $-1+\alpha$ $\frac{1}{2}+\alpha-\frac{1}{2}b$	$-\frac{1}{2}-\frac{1}{2}z+\alpha-\frac{1}{2}c$ $-1+\alpha-\frac{1}{2}c$ $\frac{1}{2}+\alpha-\frac{1}{2}b$	$-\frac{1}{2}-\frac{1}{2}z+\alpha$ $-\frac{1}{2}-\frac{1}{2}z+\alpha$ α	$-\frac{1}{2}-\frac{1}{2}z+\alpha$ $-\frac{1}{2}-\frac{1}{2}z+\alpha-\frac{1}{2}c$ α	$0l$	$-\frac{1}{2}-\frac{1}{2}z+\frac{3}{2}\alpha$ $-1+\frac{3}{2}\alpha$ $\frac{3}{2}\alpha$	$-\frac{1}{2}-\frac{1}{2}z+\frac{3}{2}\alpha$ $-1+\frac{3}{2}\alpha-\frac{1}{2}c$ $\frac{3}{2}\alpha$	$-\frac{1}{2}-\frac{1}{2}z+\alpha$ $-\frac{1}{2}-\frac{1}{2}z+\alpha$ α	$-\frac{1}{2}-\frac{1}{2}z+\alpha$ $-\frac{1}{2}-\frac{1}{2}z+\alpha-\frac{1}{2}c$ α
$0h$	$-\frac{1}{2}-\frac{1}{2}z+\alpha$ $-1+\alpha$ $\frac{1}{2}+\alpha-b$	$-\frac{1}{2}-\frac{1}{2}z+\alpha$ $-1+\alpha-\frac{1}{2}c$ $\frac{1}{2}+\alpha-b$	$-\frac{1}{2}-\frac{1}{2}z+\alpha-\frac{1}{2}c$ $-\frac{1}{2}+\alpha-\frac{1}{2}z$ α	$-\frac{1}{2}-\frac{1}{2}z+\alpha-\frac{1}{2}c$ $-\frac{1}{2}-\frac{1}{2}z+\alpha-\frac{1}{2}c$ α	$0h$	$-\frac{1}{2}-\frac{1}{2}z+\frac{3}{2}\alpha$ $-1+\frac{3}{2}\alpha$ $\frac{3}{2}\alpha$	$-\frac{1}{2}-\frac{1}{2}z+\frac{3}{2}\alpha$ $-1+\frac{3}{2}\alpha-\frac{1}{2}c$ $\frac{3}{2}\alpha$	$-\frac{1}{2}-\frac{1}{2}z+\alpha-\frac{1}{2}c$ $-\frac{1}{2}-\frac{1}{2}z+\alpha$ α	$-\frac{1}{2}-\frac{1}{2}z+\alpha-\frac{1}{2}c$ $-\frac{1}{2}-\frac{1}{2}z+\alpha-\frac{1}{2}c$ α

Table 2.3: Conditions on parameters

	L					H			
	$1l$	$1h$	$0l$	$0h$		$1l$	$1h$	$0l$	$0h$
$1l$	$c=0, z\geq 1$ $b\leq 1-\alpha$	$c=0, z\geq 1$ $b\leq \frac{2}{3}(1-\alpha)$	$c=0, z=1$ $b\leq (1-\alpha)$	$c\geq 0, z=1$ $b\leq \frac{1}{2}(1-\alpha)$	$1l$	$z\geq 1-\alpha$ $b\geq 1-\alpha$	$z\geq 1-\alpha$ $b\geq \frac{2}{3}(1-\alpha)$	$c\geq 0, z=1-\alpha$ $b\geq 1-\alpha$	$c\geq 0, z=1-\alpha$ $b\geq \frac{1}{2}(1-\alpha)$
$1h$	$c=0, z\geq 1$ $b\leq \frac{2}{3}(1-\alpha)$	$c\geq 0, z\geq 1$ $b\leq \frac{1}{2}(1-\alpha)$	$c=0, z=1$ $b\leq 1-\alpha$	$c=0, z=1$ $b\leq \frac{1}{2}(1-\alpha)$	$1h$	$z\geq 1-\alpha$ $b\geq \frac{2}{3}(1-\alpha)$	$z\geq 1-\alpha$ $b\geq \frac{1}{2}(1-\alpha)$	$c=0, z=1-\alpha$ $b\geq 1-\alpha$	$c=0, z=1-\alpha$ $b\geq \frac{1}{2}(1-a)$
$0l$	$c=0, z=1$ $b\leq 1-\alpha$	$c=0, z=1$ $b\leq (1-\alpha)$	$c\geq 0, z\leq 1$ ————	$c=0, z\leq 1$ ——	$0l$	$c\geq 0, z=1-\alpha$ $b\geq 1-\alpha$	$c=0, z=1-\alpha$ $b\geq 1-\alpha$	$c\geq 0, z\leq 1-\alpha$ ——	$c=0, z\leq 1-\alpha$ —-
$0h$	$c\geq 0, z=1$ $b\leq \frac{1}{2}(1-\alpha)$	$c=0, z=1$ $b\leq \frac{1}{2}(1-\alpha)$	$c=0, z\leq 1$ —————-	$c=0, z\leq 1$ ————	$0h$	$c\geq 0, z=1-\alpha$ $b\geq \frac{1}{2}(1-\alpha)$	$c=0, z=1-\alpha$ $b\geq \frac{1}{2}(1-\alpha)$	$c=0, z\leq 1-\alpha$ —-	$c=0, z\leq 1-\alpha$ ——-

2.3.1 $c > 0$

Assuming the citizens do care about the wrong guesses (i.e. $c > 0$), we discuss below few interesting outcomes/scenarios.

COROLLARY 2.1. *Given that the penalty of tax evasion is relatively small, i.e.*

$$0 \leq z \leq 1, \tag{2.7}$$

there exists at least one pure-strategy (tax evasion) Nash equilibrium where both citizens evade taxes.

Given the condition in equation 2.7, we have two pure-strategy (tax evasion) Nash equilibrium profiles: $((0l),(0l),L)$ and $((0l),(0l),H)$, where both citizens evade taxes and guess correctly that the governor had one unit for public good provision, and the governor provides L and H level of public good, respectively, with the latter being out of the equilibrium path. Our Corollary 1 is consistent with most of the literature on tax evasion: if the penalty on tax evasion is small, then each citizen has the dominant strategy to avoid paying taxes. The theoretical literature on tax evasion goes back to Allingham and Sandmo (1972) and Yitzhaki (1974) These studies provide simple theoretical model where individual tax payers decide whether or not to evade taxes in the presence tax enforcement (i.e. random audits, penalties, etc.). There have been extensions to these two models in various contexts and Sandmo (2005) provide an extensive review on the literature on tax evasion. A more recent study by Kleven et al. (2011) extends the model by Allingham and Sandmo (1972) and suggest that for self-reported income the empirical results are aligned with the theoretical model, i.e. tax evasion is substantial and is negatively related to an increase in penalties, probability of audit, etc. This result can also be connected to another stream of literature on sanctions in case of public good games[3].

COROLLARY 2.2. *Given that the penalty of tax evasion is high enough,*

$$z \geq 1,$$

[3] There is extensive literature on peer-punishments to improve welfare and compliance for public good games; see, for instance, Fehr and Gächter (2002), Baldassarri and Grossman (2011), Baldassarri and Grossman (2012), among others.

and the punishment for embezzlement is small, i.e.

$$0 \leq b \leq \frac{1}{2}(1-\alpha),$$

there exists a pure-strategy (embezzlement) Nash equilibrium where at least one citizen pays her taxes and the governor embezzles one unit of public good, whenever he has an opportunity to do so.

This proposition shows that high punishment for tax evasion forces citizens to pay taxes. At the same time, a small enough punishment for embezzlement encourages the governor to steal one unit. Given the conditions on b and $z(> 1)$ we have three pure-strategy (embezzlement) Nash equilibria. First, we have $((1h),(1h),L)$, where both citizens pay their taxes and guess correctly that the governor had two units for public good provision and the governor provides L level, i.e. the governor embezzles one unit of public good. For $z = 1$ (and same restriction on b as provided by Corollary 2 above) we have $((1l),(0h),L)$ and $((0h),(1l),L)$ as the PS(embezzlement)NE where only one of the citizen evades tax and the governor embezzles when the opportunity arises (i.e. when tax-evading citizen is audited resulting in $X = 2$ for the governor to re-distribute). This result is very intuitive and similar results[4] exist in the literature which examine whether some form of accountability (may be, electoral) could discourage peculation.

Corollary 2.3. *If the punishment for tax evasion in high enough,*

$$z \geq (1-\alpha),$$

and the punishment for embezzlement is high enough,

$$b \geq (1-\alpha),$$

then there exists a pure strategy (public good provision) Nash equilibrium where at least one citizen pays taxes and the governor re-distributes the entire public fund.

[4]See Welch and Hibbing (1997), Peters and Welch (1980), Reinikka and Svensson (2004), Fisman and Miguel (2007), Ferraz and Finan (2008), Barr et al. (2009), Ferraz and Finan (2011), Bobonis et al. (2016), Weitz-Shapiro and Winters (2017), among others.

This proposition demonstrates that if both punishments for tax evasion and embezzlement are high enough, then every member benefits. For $z = 1-\alpha$ (and the same restriction on b as given by Proposition 3 above), we have $((0l),(1l),H)$, $((0h),(1l),H)$, $((1l),(0l),H)$, $((1l),(0h),H)$ as the pure-strategy (public good provision) Nash equilibria of the game where only one of the citizens pay taxes (i.e. an asymmetry in the behaviour of the citizens[5]) and the governor is honest i.e. re-distributes two units of public good when the opportunity arises (if the tax-evading citizen is audited, governor has $X = 2$).
To ensure an efficient public good provision, i.e. a situation where both citizens pay taxes and the governor redistributes the entire public fund, we impose a strict restriction on z (keeping the restriction on b same as above).

COROLLARY 2.4. *For $z > (1-\alpha)$, there exists a pure strategy ('efficient' pubic good provision) Nash equilibrium where both citizens pay their taxes and the governor re-distributes the entire public fund.*

We assume $\frac{1}{3} \leq \alpha \leq 1$ for efficiency, and given the restrictions on z and b from Proposition 3 and Corollary 1, we have $((1l),(1h),H)$, $((1h),(1l,H)$, $((1l),(1l),H)$ as the pure-strategy ('efficient' public good provision) Nash equilibria of the game where both the citizens pay taxes and the governor makes high two-unit, H, public good provision and the citizens guess either l or h in this information set, which is out of the equilibrium path.

There is an extensive theoretical literature on optimal public good provision which looks at various (punishment) mechanisms (see Groves and Ledyard (1977) for details) which encourage individuals to make contributions towards the public fund. Falkinger (1995) propose incentive schemes where the government should reward (via subsidies) or penalize (via additional taxes) deviations from mean contribution in order to increase efficiency. Some more recent experimental studies[6] try to test the validity of the theoretical results to find that some form of penalties encourage contributions (or reduce tax evasion). Citizens' behaviour depends on the motivations, intentions and behaviour of the government. Empirical evidence suggests citizens are likely to evade taxes if

[5]See Erard and Feinstein (1994) and Gibson et al. (2013) for related literature.

[6]See Alm et al. (1992), Chen and Plott (1996), Falkinger et al. (2000) , Uler (2011), Robbett (2016), among others.

they believe the government will not provide good service. Citizens will comply if the government reciprocates their trust (see Luttmer and Singhal (2014), Slemrod (2007)). Casaburi and Troiano (2016) provide evidence of a positive interaction between improved tax-payer monitoring systems and political incentives, i.e. there is increase in the re-election likelihood with introduction of better auditing technologies, especially in areas where the government is more efficient in providing public goods.

2.4 Conclusion

We provide a simple unified model of tax evasion, embezzlement and public good provision and show the links between the three. Our model provides an extremely rich setting, where with the help of our four basic parameters we can describe any possible situation. The amplitude of this result enables us to extend the model in various directions (empirical, experimental and theoretical). The model and our equilibrium predictions can be tested in a laboratory experimental setup. In addition to this, the model can be tested in a field with support of some real data. One can also think of how the equilibrium behaviour of the players will change when the model is considered in a repeated setting. We postpone these ideas for future work.

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Chapter 3

Position uncertainty in a sequential public goods game: An Experiment

3.1 Introduction

Producing public goods at a socially optimal level is difficult because individual incentives and collective interest are often at odds. When contributing to a public good is costly, the possibility to free-ride on the contributions of others can be an obstacle to achieve a socially optimal outcome. Typically, to improve contribution by self-interested agents requires repeated strategic interactions over an infinite horizon (see Friedman (1971) on theoretical literature in a social dilemma setting; and see Dal Bó et al. (2010), Duffy and Ochs (2009) for experimental evidence in this direction). The public goods literature has shown that it is possible to improve contribution if the agents have non-standard preferences or agents are not fully rational (e.g., warm-glow, altruism etc) (Andreoni, 1990; Fehr & Gächter, 2000, 2002).

In this chapter, I test the prediction of the public good game made by Gallice and Monzón (2019). The authors show that full-contribution is possible in a one-shot public goods game with self-interested agents. To fix ideas, consider a public goods game with a finite number of agents. Agents contribute sequentially but do not know their position in the sequence. They are equally likely to be anywhere in the sequence. Before contributing each agent observes partial history - the total contributions of her immediate predecessors. After all agents have made their contributions, the total contribution is multiplied by the return from contributions parameter, and then divided equally among all agents.

Gallice and Monzón (2019) show that there is an equilibrium where everyone contributes if the multiplier is above some threshold.

In order to test this prediction, I conduct an online experiment with two treatments. In the first treatment, participants play a simple sequential public good game. Participants observe all previous contributions before they make their decision to contribute. This is the baseline treatment. In the second treatment, participants play a sequential game akin to Gallice and Monzón (2019). Participants are unaware of their position in the sequence and they contribute sequentially. They observe the history of their two immediate predecessors before they make their decision. In the first treatment, I find evidence that contribution, at the group level, are close to socially optimum levels. Comparing the contributions (at group level) between treatment one and treatment two, I find that contributions are much lower in the second treatment. This suggests that the results from the experiment do not support the hypothesis - contributions are higher in sequential game compared to the sequential game with position uncertainty.

There is a lot of literature on public goods games. This chapter focuses on a sequential public goods game so the paper contributes to the literature on sequential public goods game. Varian (1994) models a public goods game with sequential contribution. He compares sequential contributions with simultaneous contributions. Assuming that one player's contribution is a perfect substitute of another player's contribution, he finds that in a sequential game the first mover free rides on the subsequent players. Therefore, the total contribution in the sequential contribution will be lower than a simultaneous contribution mechanism, i.e., sequential timing lowers total contributions.

There are experimental papers comparing sequential contribution mechanism versus simultaneous mechanism. Gächter et al. (2010) designs an experiment based on Varian (1994)'s model with two players, quasi-linear returns, and complete information about returns. Their paper focuses on the asymmetry of returns from the public goods. In the first setting, they find that under sequential contribution overall provision is lower compared to simultaneous contributions and first movers do not have any advantage. In the second setting, they find evidence that second movers free ride.

Andreoni et al. (2002) did a similar experiment- comparing simultaneous and sequential games. Unlike Gächter et al. (2010), they introduce minimal asymmetry between players. They find that in early rounds the first movers were taking advantage of the second mover, but by the end of the experiment results from the simultaneous contribution game and the sequential contribution game were similar. My design is different from Andreoni et al. (2002) and Gächter et al. (2010). In my design there is no asymmetry in the return on public goods and I use more than 2 players in each public goods game. In one of my treatments, I test a new theory that predicts the possibility of full contribution in one-shot public goods game with position uncertainty. In Andreoni et al. (2002) and Gächter et al. (2010) players know their position in the game and observe complete history.

Several papers focus on endogenously determining the public goods game to play. Potters et al. (2005) studied the difference between simultaneous contribution and sequential contribution. In one of the treatments subjects voted on the mechanism - simultaneous versus sequential. In the other treatment, the mechanism was exogenously picked by the experimenter. The results from the experiment show that subjects prefer the sequential move game and the contributions are larger in the sequential move game. In my experiment, subjects do not vote for the mechanism, instead, the experimenter decides on the mechanism. Other papers along this direction include Romano and Yildirim (2001), Vesterlund (2003).

I also contribute to the literature on games with position uncertainty and observational learning. In a typical game with position uncertainty, a principal decides what information to reveal to the agents (Nishihara, 1997). In my design, agents directly observe the contributions of the predecessors.

The structure of the chapter is as follows. First, in Section 3.2, I present the theoretical foundation of the experiment. Second, in Section 3.3, I present the design of the experiment. Third, in Section 3.4, I present the results from the experiment. Finally, I conclude in Section 3.5.

3.2 Theoretical Predictions

Consider a game with $N = \{1,..,6\}$ in a group[1]. A player $i \in N$ must choose whether to contribute to a public good , i.e., $a_i \in \{1,0\}$. Action $a_i = 1$ means contributing a fixed amount 1 to a common pool, while $a_i = 0$ means contributing 0 in the common pool. Players make decisions sequentially but they have no information regarding their position in the sequence. They are equally likely to be in any position. Every player observes some sample $s = (m, c)$ of her immediate predecessors' decisions before they make their decision, where m is the number of predecessor sampled and c is the number of contributors. Let $G_{-i} = \sum_{j \neq i} \mathbb{1}\{a_j = 1\}$ denote the number of players who contribute. So $G_{-i} \in \{0,1,.....,5\}$. Therefore, payoffs $u(a_i, G_{-i})$ can thus be expressed as

$$u_i(1, G_{-i}) = \alpha(G_{-i} + 1) - 1 \quad \text{and} \quad u_i(0, G_{-i}) = \alpha G_{-i}, \tag{3.1}$$

where $\alpha = \frac{r}{6}$ is the marginal per capita return(MPCR) from the public good.

This is an extensive form game with imperfect information. Players form beliefs about their position in the sequence and about the history of the past play. Gallice and Monzón (2019) use the notion of sequential equilibrium. Player i's strategy is a function σ_i that specifies the probability of contributing given the sample received. Let $\sigma = \{\sigma_i\}_{i \in N}$ denote a strategy profile and $\mu = \{\mu_i\}_{i \in N}$ a system of beliefs. The assessment (σ^*, μ^*) is a sequential equilibrium if σ^* is sequentially rational given μ^*, and μ^* is consistent given σ^*. Given a profile of play σ, let μ_i denote player i's beliefs about past play. To understand how beliefs are formed, consider a game with only three players and a sample size of one. When a player is asked to make a decision he knows that there are seven possible histories of past play : $\{\emptyset, (1), (0), (1,1), (1,), (0,1), (0,0)\}$. Players form beliefs after receiving the sample. A player who observes $s = (1,1)$ knows that he is not in the first position. He could be in any position with the history of play that has contribution as the last action : $\{(1), (1,1), (0,1)\}$. Instead, if a player observes $m = (0,0)$ he realises that history of past play is $\emptyset$, and so he is in the first position.

[1] Please note that in Gallice and Monzón (2019)'s model there are n players. Here I describe the model with 6 players because in my experiment I will have 6 players in each group.

Let $\mathscr{H}$ be the set of all possible histories. Consider all samples without defection, and denote this by H^C. This set consists of all samples where $m = c$, i.e., the number of observed individuals m equals to the number of observed individuals who contribute. The first player in the sequence only receives a sample without defection:$(0,0) \in H^C$. First, consider a player i who observes some $s \in H^C$. This happens on the equilibrium path where everyone contributes, so players can infer that all his predecessors have contributed ; and he knows if he contributes, his successors will also contribute. Therefore his expected payoff from the contribution is $E_u[u(1, G_i)|s] = r-1$ for all $s \in H^C$. This payoff does not depend on player i's beliefs about his position in the sequence. Agent's payoff from defecting does depend on her beliefs about her position. To see this, let's assume that agent i knows her position, i.e., she knows that she is in position t. If all of her predecessor contributed, and she does not contribute, then none of her successor will contribute. This means exactly $t-1$ players contributed. The payoff from defecting will be $(r/n)(t-1)$. Figure 3.1 shows agent i's payoffs as a function of her position. It shows that the payoffs from contribution, for agents early in the sequence, is larger than from defecting. But agents placed late in the sequence prefers defection. So, if agents knew their position, contribution would unravel.

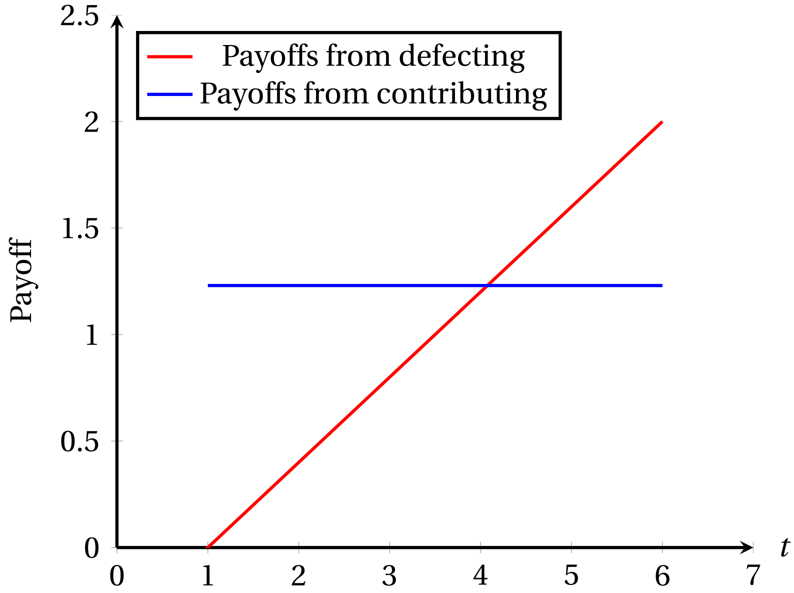
Now consider a player who observes $m \geq 2$ players contribute and she is unaware of where she is in the sequence. Then the player can deduce she is not in the first m positions, and she has the equal probability to be in in any position between m and 6. Therefore she expects to be in position $(7+m)/2$, and expects $(5+m)/2$ players to have already contributed. Therefore, her expected payoff from not contributing (i.e., defection) will be

$$\frac{r(5+m)}{12}$$

Then the contribution will require

$$r-1 \geq \frac{r(5+m)}{12}$$

and this simplifies to



Payoffs Conditional on Position and on sample without defection (where $r = 2.4$)

Figure 3.1: Illustration of why contribution would unravel

$$r \geq \frac{12}{7-m} \tag{3.2}$$

Prediction. Consider a simple profile of play where agents contribute unless they observe defection. Then, if $m \geq 2$ and $r \geq \frac{12}{7-m}$, there is sequential equilibrium with full contribution equilibrium outcome.

If sample contains $m' < m$ total actions, then the player knows she is in position $m'+1$. She can infer that the number of agents who contributed so far is m'. Therefore, the expected payoff from defecting is even lower : $(r/n)m' < (r/n)(5+m)/2$.Thus, equation (3.2) also guarantees that players in the first m positions contribute.

3.3 Experiment Design

3.3.1 Procedure

The experiment was conducted online using Amazon Mechanical Turk (mTurk), and the geographic location was restricted to the USA. The experiment was programmed in oTree (Chen et al., 2016) and was deployed to mTurk. Participants were invited to sign-up within 20 minutes of the experiment (or HIT)[2] being posted and requested them to complete the experiment in 45 minutes. The experiment was only active for 70 minutes. This was done to encourage participants to start the task immediately (see Arechar et al. (2018) on general advice to run interactive experiments on mTurk). To prevent a participant from participating twice, a 'qualification' was granted to each participant in the experiment. Then workers who were granted this 'qualification' were blocked from participating again.

Each session was designed to accommodate 12 participants[3] divided into 2 groups. To reduce drop-outs, groups were formed on the 'fly'. Groups were formed in the order they arrived. So the first 6 participants to arrive are grouped together, and the next 6 participants to arrive are grouped together. Ten sessions were run, but only 5 sessions were useful. This is because of lack of participation and dropouts. In the 5 valid sessions, it was only possible to form 1 group each session. So a total of 30 participants actively participated in the experiment.

In all the sessions, participants played a public good game for 12 rounds. The first 2 rounds were practice rounds. The public good game that the participants played in each session varied according to the treatment. Each participant was endowed with 100 points. They were asked whether they wanted to contribute all the 100 points or 0 points in a common project. The rate of return, r, was set to 2.4 so that marginal per capita return, α, is 0.4.

In all sessions, earnings were calculated as follows:

$$u_i(a_i, G_{-i}) = \alpha(G_{-i} + a_i) - a_i + e_i \tag{3.3}$$

[2]HIT or Human Intelligence Tasks are virtual tasks that a 'worker' can work on, submit an answer, and collect a reward for completing

[3]oTree automatically doubles the number of participants when a session is created. This is because spares are needed in case some MTurk workers accepts the HIT but then return the assignment.

where a_i is the participant's contribution, G_i is total contributions of other participants in each group, and e_i is the endowment.

In every session, the participants were paid after 12th round. Only one of the rounds between round 3 and 12 was picked randomly for payment (first two rounds were practice rounds). This reduces the hedging opportunities and cross-contamination between rounds (Azrieli et al., 2018; Charness et al., 2016). Participants received a participant fee of $2. In order to promote recruitment rates, participation fee was relatively high. The earnings were converted into cash so that 30 points = $1. The average earnings was $ 7.481 with a standard deviation of $ 1.167.

3.3.2 Treatments and Design

In *Treatment 1 (T1)*, subjects play a sequential voluntary contribution game. Each participant was endowed with 100 points every round. Participants were asked to contribute to a common project. Contributions could be either 100 or 0 points. The decisions were made sequentially. The computer assigned roles to each player. For example, if the role was player 1 then he/she had to make the decision first. Then, participant who got the role of player 2 makes his/her decision, then player 3 and so on. The roles were randomly determined each round. Before the participants made their decision, they were informed about the contributions made by their predecessors, and they were also informed about their role in the game. Only player 1 in the game did not receive any information regarding past play because there were no players before him. At the end of every round, subjects were informed about the contributions of each player, total contributions, their contribution, and earnings. Theoretical prediction of this treatment is that subjects will not contribute. It is easy to check by solving this sequential game by backward induction.

Hypothesis 1 In *T1*, subjects will not contribute to public goods.

In *Treatment 2(T2)*, subjects played a sequential voluntary contribution game similar to the game in T1. Each participant was endowed with 100 points every round. Participants were asked to contribute to a common project. Contributions could be either 100 or 0 points. In this treatment, subjects were not informed about their position in the sequence of play. The computer assigned roles to each player. For example, if the role was player 1 then he/she had to make the decision first. Then, the participant who got the role of player 2 made his/her decision, then player 3 and so on. The roles were randomly determined each round. Subjects were not informed about their role. They only received information about the total contribution of their 2 immediate predecessor. This means the subjects received one of the following information:

- Your 2 immediate predecessor have contributed 0
- Your 2 immediate predecessor have contributed 100
- Your 2 immediate predecessor have contributed 200

Only the subject playing the role of Player 1 did not receive any information regarding the past play. Subjects were informed about this in the instruction before the experiment began. They were also informed about what 'predecessor' meant in the instruction. At the end of every round subjects were informed about the contributions of each player, total contributions, their contribution, and earnings. Gallice and Monzón (2019) predicts that if α (marginal per capita return) is high enough and the sample of history they observe is at least 2, then there exists an equilibrium where everyone contributes. Therefore, I expect, in treatment 2, there will be more contributions compared to sequential game in treatment 1.

Hypothesis 2 In *T2*, total contributions in each group will be higher compared to sequential game in Treatment 1.

3.4 Results

In this section, I present the results of the experiment. The descriptive statistics in Table B.1 for Treatment 1 shows that mean contributions at group level is almost close to maximum level of contribution at the group level. While, in

Table B.2, for Treatment 2 the mean contribution at group level is 475. This pattern is more evident if we look at group contributions across rounds (see 3.2). In Treatment 1 Contributions at group level were close to full contribution level almost every round. Whereas, in Treatment 2, there is an upward trend on contributions at the group level. Overall, the descriptive statistics suggest that contribution levels in Treatment 1 is higher than contributions level in Treatment 2.

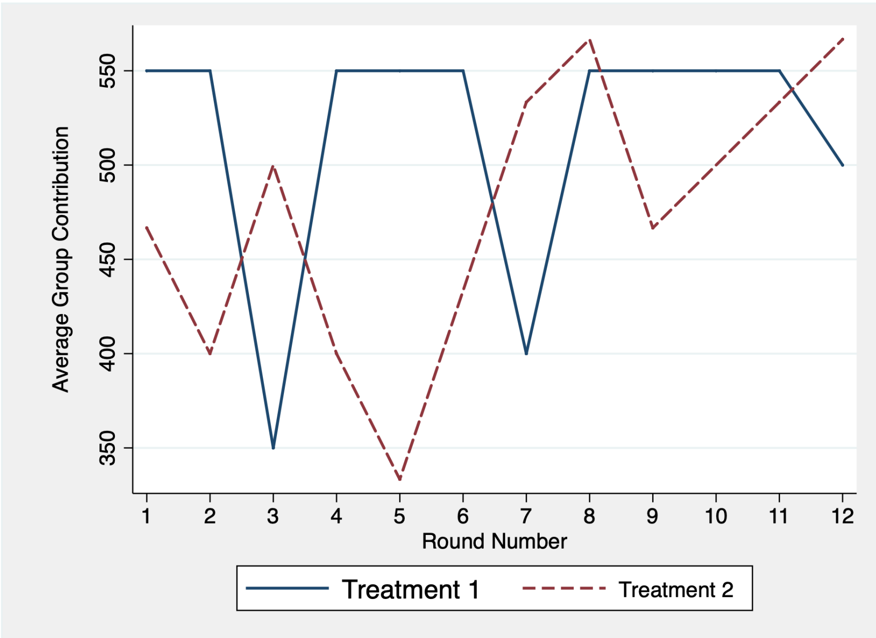


Figure 3.2: Average contributions across rounds

Comparing the medians of the two treatments (see Figure 3.3) suggests that contributions are much higher in Treatment 1. In Figure 3.3 we can see that median contributions in Treatment 1 is 550, whereas the median contributions in Treatment 2 is 500. A two-tailed Wicoxon-Mann-Whitney test suggests that this difference is significant at any level (see TableB.4). This does not support my second hypothesis that contribution levels will be higher in Treatment 2 compared to Treatment 1 . My first hypothesis was that in Treatment 1 participants will not contribute to public goods. A two-tailed t-test of contributions (at group level) suggests that this is not true at any significant level (see B.3. Overall, the results can be summarized as follows:

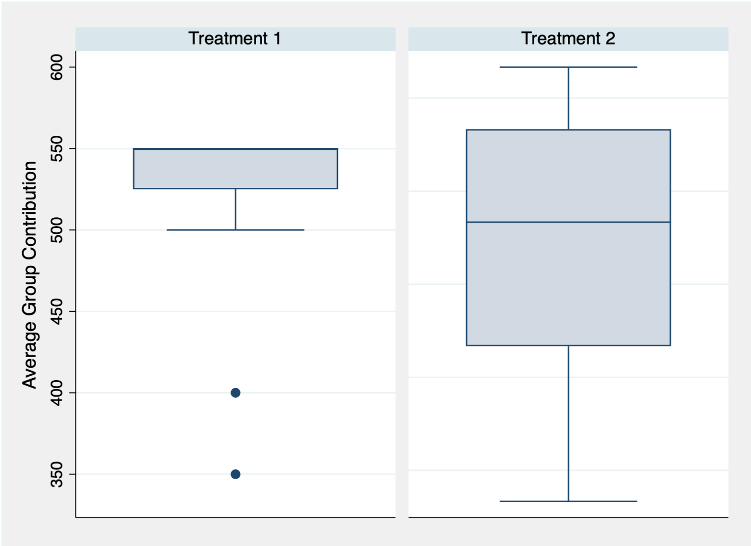


Figure 3.3: Box plot : comparing contributions at group level

Result 1. There is no evidence to suggest that in a sequential move public goods game contributions will be zero.

Result 2. Contributions at group level in a sequential game is significantly higher than sequential game with position uncertainty.

The prediction in Section 3.2 was based on a profile of play where players contribute unless they observe defection (similar to a grim-trigger strategy). This means that the contribution of the player playing first is crucial and would dictate the future play. To check the significance of the first mover, I do a regression analysis where the dependant variable is individual contributions and the main variable of interest is First Mover. Table 3.1 reports the results. In Table 3.1, First Mover is a dummy where it takes the value of 1 if the first mover contributed, otherwise it takes a value of zero. The first column reports regression for all the rounds, and the second column reports results from Rounds 3-12 (since the first two rounds are practice rounds). The results show that the first mover do play a significant role on the individual contributions.

Table 3.1: Regression analysis of Treatment 2

	All Rounds Contribution	Rounds 3-12 Contribution
First Mover	23.31**	22.07**
	(7.775)	(8.156)
Round	1.892*	2.436*
	(0.779)	(0.998)
Constant	63.63***	59.10***
	(5.789)	(8.067)
Observations	216	180
Adjusted R^2	0.060	0.061

Standard errors in parentheses

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

3.5 Conclusion

In this chapter, I presented an experiment comparing two different sequential public goods game. The experiment result shows that contributions in a sequential move public goods game is higher than predicted. In a sequential move public goods game with position uncertainty, theory predicts that there is an equilibrium with full contribution. This prediction leads to the hypothesis that contributions in this game will be higher than the classic sequential game (in Treatment 1). But, the experiment results show that median contribution, at group level, is lower in the sequential game with position uncertainty. Future extension of this research includes adding more treatments and running more sessions on Treatment 1 and Treatment 2. One possible treatment could be having a treatment where participants only observe one predecessor's decision, instead of two. If a player observes one sample, then Gallice and Monzón (2019) predict that a (possibly) mixed equilibrium generates full contribution. Another treatment could be a game with simultaneous moves.

3.6 References

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Appendix A

Chapter 1 : Appendix

A.1 Example

Consider a game with $n = 3, \tau = 2$, and $k = 1$. If citizens 2 and 3 pay taxes with probability $p \geq 0$ and the governor uses a cut-off strategy to provides 2 units of public goods, citizen 1's expected utility from paying the tax is

$$E u_1((1,2),(p,2),(p,2);\langle 2\rangle) = -\frac{2}{3}a\left(p^2 - 2p - 2\right) - 1 \tag{A.1}$$

Assuming citizen 2 and 3 pay taxes with probability p and the governor provides 2 units of public good, citizen 1's expected utility from evading tax is given by:

$$E u_1((0,2),(p,2),(p,2);\langle 2\rangle) = \frac{1}{3}(-2a(p-4)p - z - 1) \tag{A.2}$$

Equating (A.1) and (A.2) and simplifying gives us a value of z which makes citizen 1 indifferent between paying or evading taxes, i.e.,

$$z = 2(2ap - 2a + 1) \tag{A.3}$$

Given (1.1), we have,

$$p = \frac{\tau - k}{n - k} = \frac{1}{2},$$

which gives us

$$z = 2 - 2a$$

from (A.3), and given $z \geq 0$, we have $a \leq 1$.

Assuming the citizens pay taxes with probability p, for the profile $((0,2),(p,2),(p,2);\langle 2\rangle)$ to be a symmetric MSNE, we want the Governor's best response to be his cut-off strategy, $\langle 2\rangle$, i.e.

$$E\,u_G((p,2),(p,2),(p,2);\langle 2\rangle) \geq E\,U_G((p,2),(p,2),(p,2);0)$$

where

$$E\,u_G((p,2),(p,2),(p,2);\langle 2\rangle) = 2p(-a(p-2)+p-1)-3b(p-1)^2+1$$

and

$$E\,u_G((p,2),(p,2),(p,2);0) = 1+2p-3b$$

Given $p=\frac{1}{2}$, we have

$$b \geq \frac{2}{3}(1-a)$$

Appendix B

Chapter 3 : Appendix

B.1 Statistical Tables

Table B.1: Summary statistics of Treatment 1

Variable	Mean	(Std. Dev.)	Min.	Max.
Player ID in Group	3.5	(1.714)	1	6
Participant ID	17	(8.718)	2	30
Round Number	6.5	(3.464)	1	12
Participant Payoff	228.333	(28.92)	200	300
Contribution	86.111	(34.704)	0	100
Group Total Contribution	516.667	(98.945)	200	600
Group Individual Share	206.667	(39.578)	80	240
N		144		

Table B.2: Summary statistics of Treatment 2

Variable	Mean	(Std. Dev.)	Min.	Max.
Player ID in Group	3.5	(1.712)	1	6
Participant ID	14.5	(8.507)	1	29
Round Number	6.5	(3.46)	1	12
Participant Payoff	224.444	(35.077)	160	260
Contribution	79.167	(40.706)	0	100
Group Total Contribution	475	(111.751)	200	600
Group Individual Share	190	(44.701)	80	240
N		216		

Table B.3: t-test for Treatment 1

Variable	Obs Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]
Group Contribution	144 516.6667	5.487147	65.84576	505.8203 527.5131

t = 94.1594

degrees of freedom = 143

p=0.0000

Table B.4: Wilcoxon-Mann-Whitney two-tailed test

Treatment	obs	ranksum	expected
1	144	32040	25992
2	432	32940	38988
combined	360	64980	64980
	z= 6.365		
	Prob>|z| = 0.0000		

B.2 Instructions

Group Decision Making (HIT Details) Requester Chowdhury Mohammad Sakib Anwar HITs 0 Reward $2.00 Time Allotted 70 Min

You must accept this Requester's HIT before working on it. Learn more

Title of the study : Group decision making.

Payment : A flat fee of $2.0 upon completion plus bonus that depends on you decisions and the decision of others.

What this study is about :

This is a study about group decision making from Lancaster University(UK). You will make decisions for which you will receive a bonus dependant on your and others' decision, in addition to a flat payment of $2 for completing the study.

Voluntary participation and confidentiality :

Participation in this study is entirely voluntary and may be withdrawn at any given moment without further consequences. All decisions will be made anonymously.

Browser Compatility : This HIT will not work on Internet Explorer.

Risks : To our knowledge there are no risks involved in participating in this study.

Informed Consent :

By accepting this HIT you give us informed consent that we can use your answers in anonymized form for research purposes only.

- Groups of 6 real people recruited via MTurk
- 45 MINUTES REQUIRED WITHOUT INTERRUPTION, **STARTING IMMEDIATELY** .

After you have accepted this HIT, the URL to the study will appear here: **link**.

On the last page, you will be given a completion code. Please copy/paste that code below.

Enter your completion code here

You must ACCEPT the HIT before you can submit the results

Report this HIT ▾ | Why Report ▾

Skip Accept

Figure B.1: MTurk Page

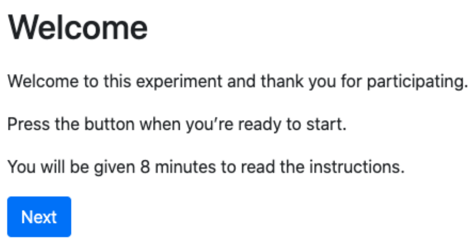


Figure B.2: Welcome Screen

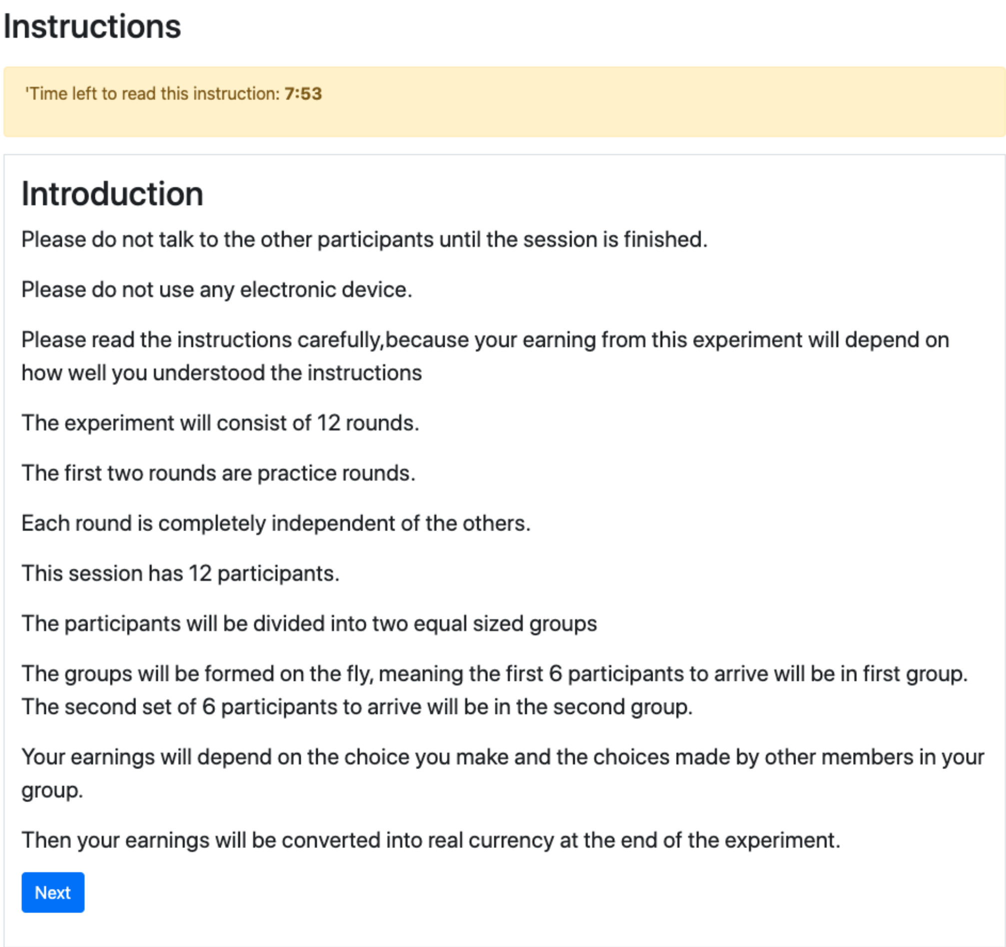


Figure B.3: General Instruction for all Treatments

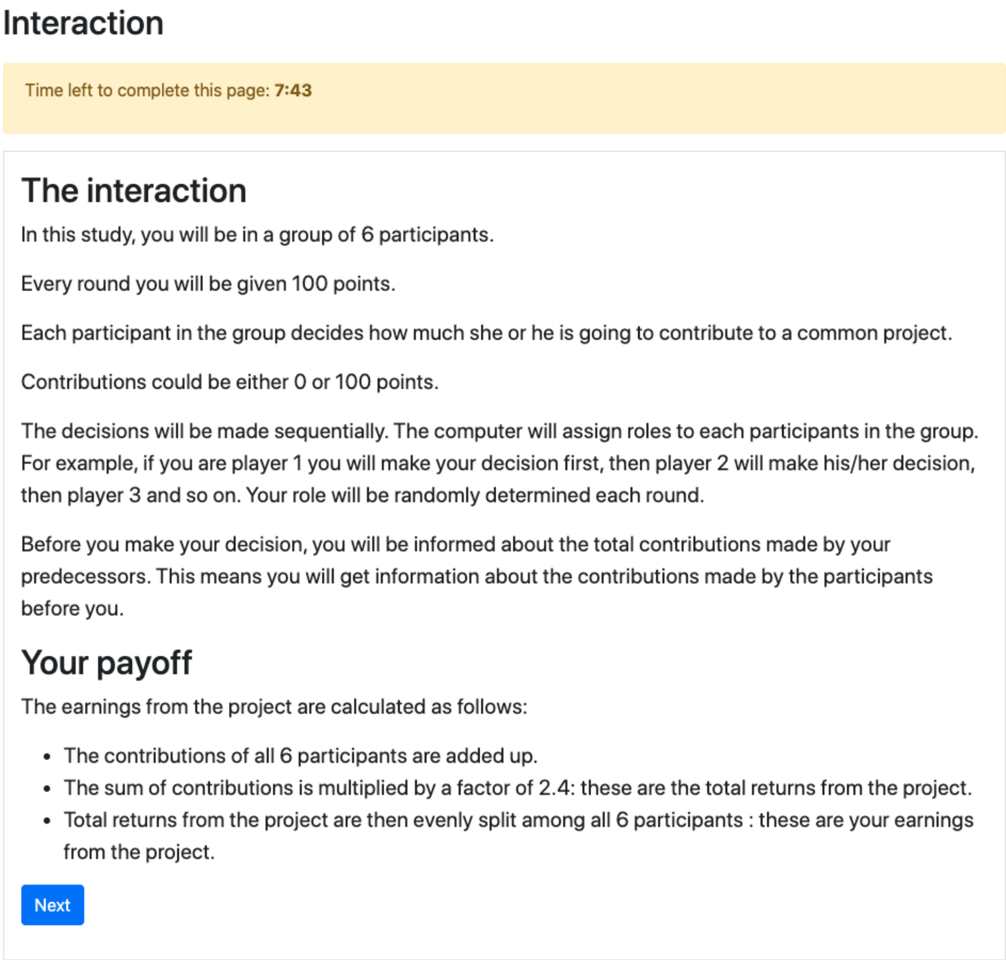
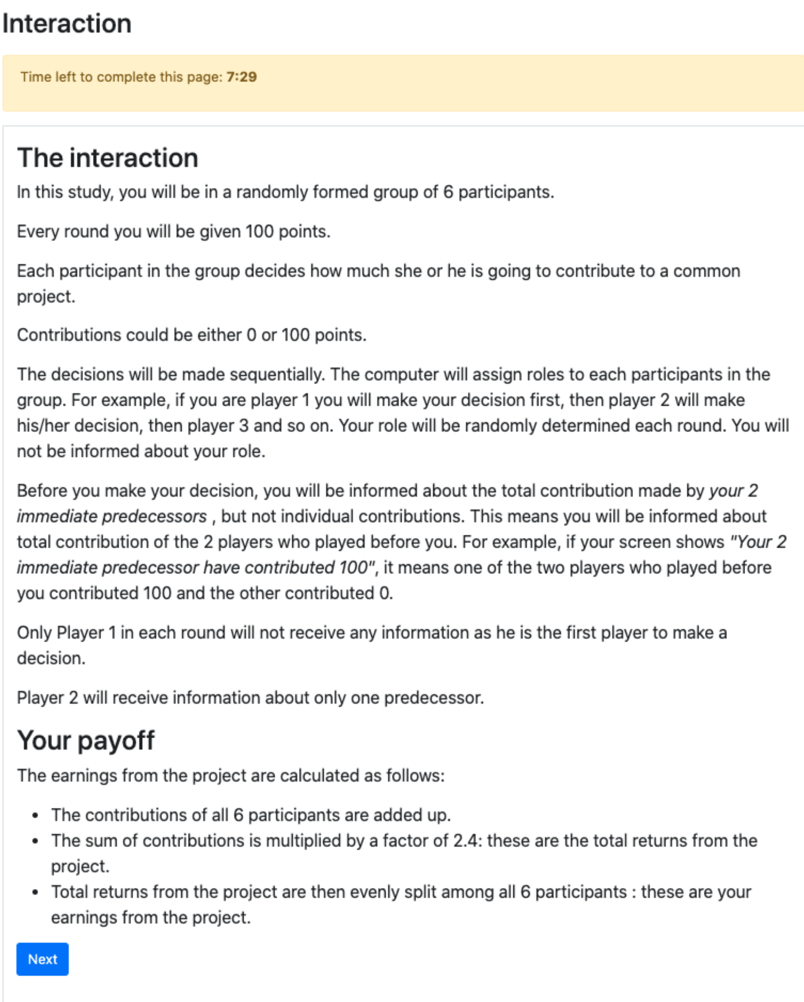


Figure B.4: Treatment 1 instructions



Interaction

Time left to complete this page: **7:29**

The interaction

In this study, you will be in a randomly formed group of 6 participants.

Every round you will be given 100 points.

Each participant in the group decides how much she or he is going to contribute to a common project.

Contributions could be either 0 or 100 points.

The decisions will be made sequentially. The computer will assign roles to each participants in the group. For example, if you are player 1 you will make your decision first, then player 2 will make his/her decision, then player 3 and so on. Your role will be randomly determined each round. You will not be informed about your role.

Before you make your decision, you will be informed about the total contribution made by *your 2 immediate predecessors* , but not individual contributions. This means you will be informed about total contribution of the 2 players who played before you. For example, if your screen shows *"Your 2 immediate predecessor have contributed 100"*, it means one of the two players who played before you contributed 100 and the other contributed 0.

Only Player 1 in each round will not receive any information as he is the first player to make a decision.

Player 2 will receive information about only one predecessor.

Your payoff

The earnings from the project are calculated as follows:

- The contributions of all 6 participants are added up.
- The sum of contributions is multiplied by a factor of 2.4: these are the total returns from the project.
- Total returns from the project are then evenly split among all 6 participants : these are your earnings from the project.

Next

Figure B.5: Treatment 2 instructions

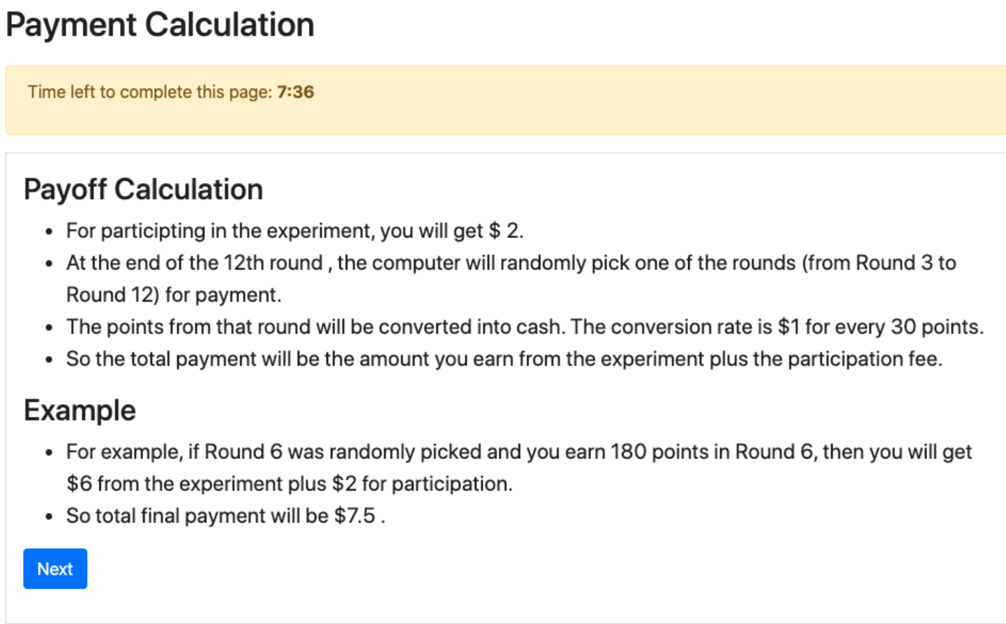


Figure B.6: Payment Instructions

Figure B.7: Wait Screen

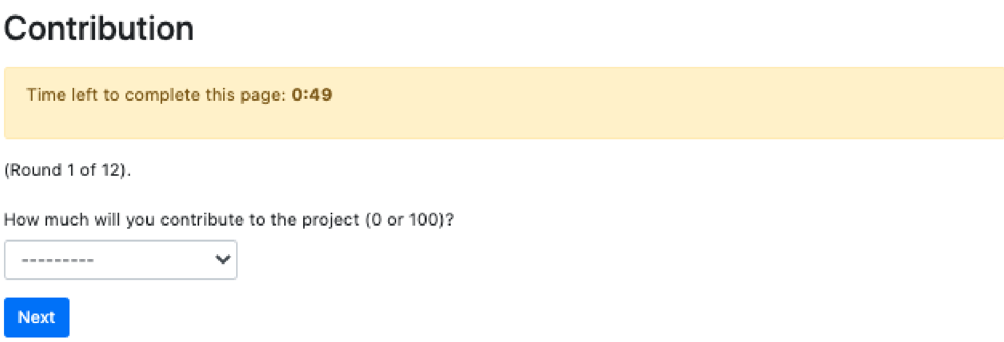


Figure B.8: Player 1's screen in Treatment 2

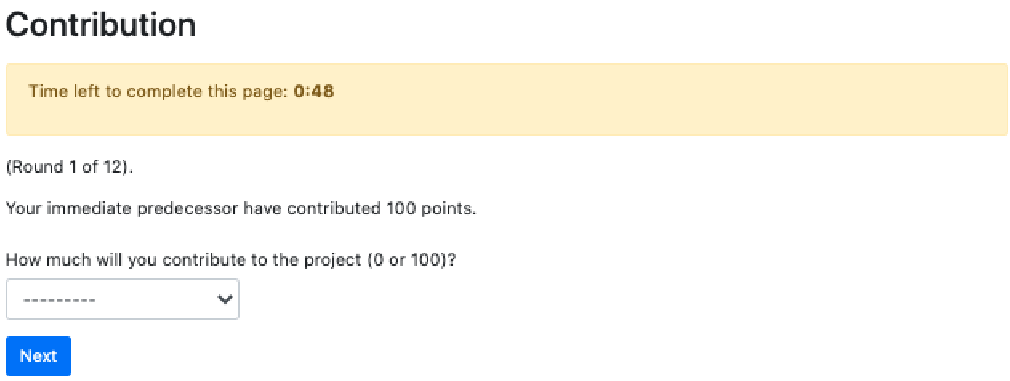


Figure B.9: Player 2's screen in Treatment 2

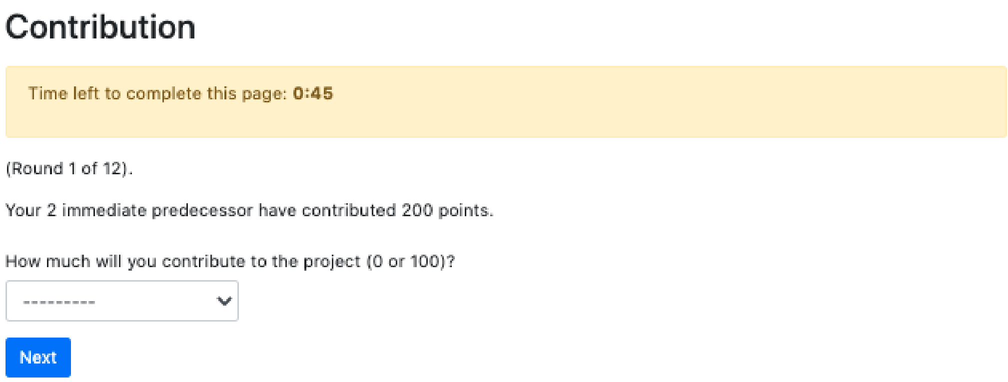


Figure B.10: Player 3's screen in Treatment 2