Competition, class-consciousness or cooperation: which motivates more?

Evidence from a bi-level combined mechanism

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COMPETITION, CLASS-CONSCIOUSNESS OR COOPERATION: WHICH MOTIVATES MORE? EVIDENCE FROM A BI-LEVEL COMBINED MECHANISM

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30 ECTS thesis submitted in partial fulfillment of a
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Abstract

This thesis consists of two separate studies of models of public good production. The first study is a baseline cross-cultural replication of the *Group Based Meritocracy Mechanism* (GBM) by Gunnthorsdottir et al. (2010a). Experimental data collected using Icelandic subjects is compared to data previously collected using US subjects. The results show that despite cultural differences, subjects from both countries respond similarly to the incentive structure of the GBM and possess the same ability to coordinate its *near-efficient equilibrium* (NEE). Without communicating and within very few trials, subjects from both countries are successfully able to coordinate this complex asymmetric Nash equilibrium.

In the second study a new model, based on the GBM, is proposed where players are segregated into two or more *endowment classes* and each endowment class has the possibility to form uniform collaborative groups. This *extended mechanism* and the implications of its novelties are analyzed in detail and an overall Nash equilibrium solution, called the *multi-tier equilibrium* (MTE), is proposed. The MTE describes possible combinations and types of *social strata* that players form depending on the society class structure. An experimental test of the extended mechanism reveals that even with a stratified society, subjects in a GBM social stratum continue to coordinate an NEE. However, subjects in a top tier VCM stratum collaborate considerably more than what is typically observed in VCM experiments.

Keywords: experiment, near-efficient equilibrium, payoff dominance, tacit coordination, mechanism design, voluntary contribution mechanism, cross-cultural

JEL: D20, C72, C92

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Abbreviations

Abbreviations for types of games

GBM	Group Based Meritocracy Mechanism
MEG	Market Entry Game
UG	Ultimatum Game
VCM	Voluntary Contribution Mechanism

Abbreviations for types of Nash equilibria

NBA	Equilibrium of no contribution by all (None By All)
NEE	Near Efficient Equilibrium
MTE	Multi-Tier Equilibrium

Miscellaneous abbreviations

ADP	All Decisions Paid
MPCR	Marginal Per Capita Return
ISK	Icelandic Krona
USD	United States Dollar

Variable names

N	The number of players in a game or the number of subjects within a single session
n	The number of players or subjects in each group or cooperative unit
z	The number of free riders in a GBM mechanism
G	The number of groups in a GBM mechanism
g	The public account multiplier
p	The private account multiplier
w_i	The endowment (wealth) or number of tokens for subject i or endowment class i per round
x_i	The contribution or allocation decision of subject i for a particular round
y	The sum of all subject contributions x in a particular group
π_i	The payoff or token profit of subject i for a particular round
τ_c	The number of subjects belonging to the endowment class c (type count)
$\bar{x}$	The mean contribution of all subjects in a single round
$\mathcal{C}$	The set of all endowment classes in case of heterogeneous endowments

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1. Introduction

We frequently encounter situations where cooperation can yield a more desirable outcome than individual effort. Such situations occur in our daily lives with our family members, friends, coworkers and even strangers. Most of humanity's greatest accomplishments are the results of joint efforts and could not have been achieved by a single individual. Firms and municipalities exist based on the premise that together, people are capable of doing something they would otherwise not. However, effort levels of collaborators are not always equal, whether it is due to different capabilities or different motivations. In some cases there is no mechanism available to link individual rewards to their contribution to the task or to exclude particular members from enjoying the produced good. In such public goods settings, a lack of proper enforcements or incentives to contribute often leads to free-riding behavior (Hardin, 1968). In turn, if free-riding behavior is widespread enough, the more cooperative members may frustratedly (see e.g. Gunnthorsdottir et al., 2007) reduce their contribution levels ending in a situation where nothing gets produced at all.

While public good production is often associated with government provided social welfare or privately funded charities one can also use the concept to describe situations where fewer people are involved as beneficiaries or contributors. Everyday examples include jobs where coworkers undertake projects and receive appraisals as a team or when students hand in group assignments. In many cases, members of various voluntary interest groups, such as parent-teacher associations, provide non-excludable services that can be enjoyed by others than the contributing members. While some may suggest that such a dilemma should be solved by incorporating market mechanisms, there may be times where a market solution may run counter to ethical or political considerations or may simply be less efficient, too costly or not possible at all.

In cases when cooperation either increases efficiency or is simply necessary for the task to be completed we must disapprove of factors that impede cooperative behavior and cause unsatisfactory or less beneficial outcomes. In order to increase welfare, these factors must be identified and either eliminated or countered with institutional arrangements that discourage free-riding behavior. By designing and experimentally testing game theoretical models of such situations, scientists may gradually identify proper methods to ensure that people favor cooperation when it is mutually beneficial. The end result may be a jointly better outcome and better use of resources.

A common method to model the provision of public goods is the *Voluntary Contribution Mechanism* (VCM) of Isaac et al. (1985). The Nash equilibrium prediction of the VCM is the least efficient solution where there is no cooperation and no production of a public good. While many subjects tend to contribute some amount in experimental settings, contribution levels are still very low. Contributions in the first round are typically only half of what is optimal and decrease as more rounds are played (see e.g. Ledyard, 1995). Various attempts have been made to modify the VCM in order to encourage contributions and improve efficiency[1]. One of these advancements of the VCM is the *Group Based Meritocracy Mechanism* (GBM) of Gunnthorsdottir et al. (2010a) where players are assortatively grouped by how much they contribute to the public good. The GBM has a *near-efficient equilibrium* which approaches full Pareto efficiency as the number of players increases. This equilibrium was successfully coordinated experimentally using US students as subjects. However, it has not been concluded whether the results are culture dependent.

This thesis consists of two separate but related experimental studies of game theoretical models of public good production where members are assortatively matched and grouped under conditions of competition by their tendency to contribute. The first study is a replication of the original GBM paper by Gunnthorsdottir et al. (2010a) where the objective is to test the robustness of prior results under an alternative cultural setting. The second study explores how different endowment levels affect the equilibrium of the GBM. While heterogeneous endowment levels had previously been explored by Gunnthorsdottir et al. (2010b), a different endowment distribution is considered. In Gunnthorsdottir et al. (2010b) the number of players of each endowment level did not match the number of players in each group meaning that in one group there would inevitably be a mix of player types. Here the number of players in each group was chosen to open the possibility of homogeneous groupings of player types, given that the players follow the necessary strategies for this grouping to be formed. Since this greatly alters the equilibrium analysis, a new model is proposed.

The thesis proceeds as follows. A general theoretical background is followed by a description of the experimental method used when collecting the data for this thesis. Next the two studies will be covered; first the baseline replication study and next the study with heterogeneous endowments. Finally there is a summary of conclusions and discussions. The appendix holds more detailed information on the experimental procedures and instructions.

[1]For an overview see e.g. Ledyard 1995, Zelmer 2003, Cinyabuguma et al. 2005.

2. Related literature

A characteristic trait of public goods provision or most group effort is the social dilemma brought on by the conflict of group interest and individual interest. An early attempt to solve this dilemma was by Lindahl who, in 1919, suggested a bargaining solution where each individual would pay for the public good a *tax* equal to her marginal benefit from the public good (Böhm, 1987). While being fair and efficient, the solution by Lindahl failed to recognize people's incentives to *understate* their marginal benefit from the public good in order to reduce their cost. Doing so, a person could reap the benefits of the public good without contributing a proportional share to its production. The belief that people are generally inclined to minimize their contribution to the production of a public good while fully consuming it at the same time is typically called the *free-rider hypothesis* (Hardin, 1968; Olson, 1971). In the words of Olson (1971, p. 21)

> *Though all of the members of the group therefore have a common interest in obtaining this collective benefit, they have no common interest in paying the cost of providing that collective good.*

The free-rider hypothesis is based on classical economic notions of self-interested rational actors who typically seek only to maximize their monetary gain. Therefore, Nash equilibria typically predict free-riding in public goods games. Early on the free-rider hypothesis did not however go undisputed (see e.g. Brubaker, 1975) and finding support for or against its existence was the theme of public goods experiments throughout the 1970's. Early experiments found surprisingly high levels of cooperation among subjects (see e.g. Marwell and Ames, 1979, 1980), to a point where the free-riding hypothesis seemed refuted. The overview by Ledyard (1995) provides a thorough overview of the classic public goods literature.

It was not until the advent of the *voluntary contribution mechanism* (VCM) of Isaac et al. (1984, 1985), played over repeated rounds, that ample evidence of free-riding was found in public goods experiments. As free-riding behavior is an undesirable attribute of public goods provision, much of the later literature has been focused on how contributions can be increased (see Zelmer, 2003). The following sections describe the game theoretical models that are applied and expanded upon in the subsequent chapters. First there is a section describing the VCM. Afterwards there is a section describing an extension to the VCM which is the primary model used in this thesis and in which contributions are substantially higher, the *group based meritocracy mechanism* (GBM).

2.1. The Voluntary Contribution Mechanism

The increased free-riding behavior observed in VCM experiments has primarily been attributed to the fact that subjects' choices were repeated whereas earlier experiments were single-round (Ledyard, 1995). Additionally, Isaac et al. (1985) introduced a larger strategy space and were careful to avoid any sort of framing. The objective was to rid the payoff function of any incentives, other than the pure monetary payoff resulting from the mechanism, that might possibly affect subject behavior. Despite a better controlled payoff function, the VCM still failed to support the *strong free-riding* predictions of traditional rational actor models and managed to only show signs of *weak free-riding*[1] of subjects. Since its inception, the VCM has been extensively researched and it has become the most established method of modeling the provision of public goods[2].

In the VCM a number of players, whose count is denoted by N, form a single group of $n = N$ players who collaborate and share each others effort in the production of a public good. The players each receive in every round an amount w of experimental tokens, henceforth called the players' *endowment*, to allocate in proportion or in whole to either a private or a public good[3]. Each player i chooses an $x_i \in [0, w_i]$ of experimental tokens to contribute to the public good. The remaining $w_i - x_i$ is committed to the subjects' private good. The total provision of endowments to the public good, y, is the sum of the contributions of all n group members

$$y = \sum_{i=1}^{n} x_i \tag{2.1}$$

After the amounts that the players contribute to the public good have been added up, the sum is multiplied by a factor g and then divided evenly among all players in the group. The portion of endowments that was invested in the private good gets multiplied by a factor p which normally is chosen to be equal to one and thus left redundant. By having the contributions to the public good multiplied by a factor g which is greater than p one implies that a players effort is more efficiently used producing a public good than a private good[4]. The payoff function for each subject i is represented by the following equation

[1] While Brubaker (1975) originally defined strong free-riding as contributing nothing and weak free-riding as contributing less than the Pareto optimum, Isaac et al. (1984) define strong free-riding as contributing less than a third of one's endowment and weak free-riding as contributing less than two-thirds.

[2] The VCM more specifically models an *impure* public good (Buchanan, 1965) because, while all group members can enjoy the public good (i.e it is non-excludable), the marginal benefit decreases when the group size increases (i.e it is rival).

[3] In order to reduce framing in experimental instructions the subjects are commonly asked to allocate their endowment to either a private or a public *account*.

[4] This is a manifestation of the common observation that together, people are capable of doing things that they cannot do alone.

$$\pi_i = p(w_i - x_i) + g\left(\frac{y}{n}\right) \tag{2.2}$$

From equation 2.2 one can derive the marginal benefit that each player receives when the sum of contributions to the public good, y, is increased. The derivative of the payoff function in equation 2.2 with respect to y gives what is called the *marginal per capita return* (MPCR) or MPCR $= g/n$. In order for the VCM to model a social dilemma, the following condition must hold

$$p > \text{MPCR} > \frac{1}{n} \tag{2.3}$$

When equation 2.3 holds, each individual player receives *less* than one token for each one she contributes but the Pareto optimal solution is still for each player to contribute her total endowment. When MPCR $= 1/n$ there are no additional benefits from mutual cooperation and if MPCR $< 1/n$ mutual cooperation effectively reduces welfare. Isaac and Walker (1988b) found, as one might expect, that the value of the MPCR is a determining factor for the level of cooperation in the VCM. The higher the MPCR, the more players cooperate and vice versa.

A single, inefficient equilibrium

The single Nash equilibrium predictions for the VCM model is that no player will ever contribute any tokens and that no public good will be produced. Since free-riding is costless[5] it is rational for each individual player to free-ride off of other players' contributions. This leads to an equilibrium of *no contribution by all* (NBA). However, in experimental settings subjects do not play this equilibrium. In fact repeated trials show that subjects *do* contribute to an extent that it cannot be explained by error alone (Andreoni, 1995). Common patterns are for contributions to be on average at around 50% of subject's total endowments in the first round which only indicates weak free-riding behavior. Still, this surprising cooperation level does not seem to be sustainable and contributions decrease as more rounds are played, usually averaging at about 20% of endowments after 10 rounds of play (for an overview see e.g. Ledyard, 1995; Zelmer, 2003). Gunnthorsdottir and Rapoport (2006) show that even with 80 rounds of play, contribution levels are still at 13% on average in the last round indicating that, while declining throughout rounds, cooperation does not seem to perish.

While experimental results of the VCM show that peoples' inclination to provide a public good voluntarily is greater than standard economic models predict, the contribution levels do not seem to be possible to sustain and efficiency is far from being Pareto optimal.

[5] Free-riding is certainly costless in the short run but it may incur cost in the long run if free-riding discourages others from cooperation.

Increasing cooperation in the VCM

For the past thirty years, scientist have tried to introduce a multitude of factors into the VCM model in order to determine the impact these factors may have on cooperation levels, with a varying degree of success. A meta-study by Zelmer (2003) reported that some factors do not seem to have any measurable effect on cooperation levels, such as group size[6], number of rounds or gender. Zelmer however found that subjects who either have prior experience with playing the game or have been asked what they believe other subjects will do tend to contribute *less* than others and when subjects are provided with heterogeneous endowments, cooperation levels suffer.

Perhaps the simplest way to raise cooperation levels is to increase the marginal return of cooperation by choosing a higher MPCR (Gunnthorsdottir et al., 2007). However, a higher MPCR does not tackle the underlying issue at hand, that subjects fail to coordinate a Pareto optimal solution and rather opt for a less efficient outcome. In real world scenarios the returns from cooperation are often fixed or not under one's control. From a policy perspective we must therefore look for *institutional* changes. Isaac and Walker (1988a) and Sally (1995) show that allowing communication between subjects can increase cooperation substantially but that is not a robust method for increasing cooperation since "cheap talk" does still not make cooperation rational. Furthermore, communication can be difficult when large groups of people must cooperate which may make it situationally dependant. Fehr and Schmidt (1999) and Cinyabuguma et al. (2005) show that by punishing defectors one can enforce cooperation upon subjects. Still, punishment schemes often depend on subjects being willing to altruistically bear the cost of punishing their peers[7]. In case a lot of discipline is needed, punishment may effectively *reduce* efficiency. Positively framing the game can have a noticeable effect on cooperation (Zelmer, 2003) but one may ask whether efficiency enhancing cooperation should depend on fragile frames instead of tangible material incentives. Lastly, by repeatedly grouping the same subjects together, i.e. partners design, cooperation levels seem to improve (Zelmer, 2003). That method still suffers from the same fundamental drawback that characterizes all the above mentioned factors that improve cooperation; it fails to offer a Nash equilibrium with positive contributions.[8]

[6]While varying the MPCR does have an effect, altering the group size, n, while keeping the MPCR constant does not. The MPCR can be held constant while group size is being altered by adjusting the public good multiplier, g.

[7]In naturally occurring circumstances the cost does not necessarily have to be financial. An ardent teammate may suffer a social cost by pestering her comrades into contributing.

[8]This discussion is reminiscent of the disparity between moral *sentimentalism* (e.g. David Hume) and moral *rationalism* (i.e. Kantian ethics). Do we put our faith in peoples sentiments or do we instill a rule based mechanism?

2.2. The Group Based Meritocracy Mechanism

The Group Based Meritocracy Mechanism, henceforth GBM, was originally introduced and experimentally tested by Gunnthorsdottir et al. (2010a). The GBM is an extension of the standard linear VCM which incorporates competitive grouping of players based on their contributions. Formally incorporating competitive group formation into a team game increases a model's external validity since under naturally occurring circumstances, most groups are consistently on the lookout for high-contributing members. Incorporating this feature into a team game however, complicates its equilibrium structure. The GBM differs from the other extensions to the VCM in that it introduces an alternative Nash equilibrium in pure strategies where cooperation becomes a rational strategy, even from the perspective of traditional rational actor models.

While the NBA equilibrium of the VCM persists, the GBM also contains a second *near-efficient* equilibrium which asymptotically approaches full efficiency. The near-efficient equilibrium is payoff dominant and should as such be jointly preferred by all players (Harsanyi and Selten, 1988). Still, since this equilibrium is both asymmetric and not particularly obvious without a formal analysis, it is quite difficult for experimental subjects to coordinate it in a standard experimental setting where decisions are simultaneous and communication is not allowed.

As in the standard VCM, all N society members decide how much of their individual endowment w to keep for themselves and how much to contribute to the public good. The distinct feature of the GBM is that after having decided their public good contribution, all N players get ranked according to their contribution with ties broken at random. Based on this ranking, participants are partitioned into G number of groups of size n, so that the highest ranking $n = N/G$ players are grouped together, then the next n players, and so on. Within each group of the GBM, players effectively interact in a standard VCM but the competition for group membership adds a layer that makes the model more complex.

At the end of each round, contributions to the group public good are, as in the VCM, summed up over all n group members, multiplied by g and then disbursed equally to all members of the group, independent of their individual contribution. Funds that players keep for themselves get multiplied by p. Recall that in the VCM all society members N belong to a *single* group while in a GBM players are divided into G number of groups. Since group membership can affect the return of a player it must be accounted for in the payoff function. Apart from accounting for group placement, the payoff function for a player in a GBM is essentially the same as for a player in a VCM (see equation 2.2). With i representing the players rank after sorting by contribution, the payoff function is represented by

$$\pi_i = p(w_i - x_i) + \frac{g}{n} \sum_{j=i-[(i-1) \mod n]}^{i-[(i-1) \mod n]+n-1} x_j \tag{2.4}$$

In the GBM, equation 2.3 still describes the condition necessary for the game to be a social dilemma. As long as equation 2.3 holds, efficiency is maximized when all players N contribute w to the public good. The MPCR continues to measure the benefit of cooperation. Mutual cooperation yields no additional benefit when $\text{MPCR} = 1/n$ and in case $\text{MPCR} < 1/n$ cooperation decreases welfare.

The GBM's Two Pure-Strategy Equilibria

Gunnthorsdottir et al. (2010a) show that, given a continuous strategy space, there exist two pure strategy Nash equilibria in a GBM; *no contribution by all* (NBA) and the *near efficient equilibrium* (NEE). The strategy profiles for each equilibrium are henceforth depicted by S_{NBA} and S_{NEE} respectively. Gunnthorsdottir et al. (2010a) also discovered mixed strategy equilibria but show that experimental subjects do not play these[9]. With a discreet strategy space there may additionally exist a number of Nash equilibria with very low contribution levels. The existence and configuration of these equilibria depend on the chosen parameters, mainly the value of the MPCR (see Gunnthorsdottir et al., 2010a, online appendix B). Given that subjects make investment decisions with a margin of error, the low contribution levels make these equilibria impossible to distinguish from the equilibria of *no contribution by all* in an experimental setting. These additional equilibria will therefore not be discussed further here.

The GBM inherits the *no contribution by all* equilibria from the standard VCM game in which S_{NBA} is the single Nash equilibrium strategy profile. As with the VCM, the *no contribution by all* exists in the GBM as long as it models a social dilemma, per equation 2.3, but the *near efficient equilibrium* is specific to GBM type games. However Gunnthorsdottir et al. (2010a) show that the existence of the NEE in a GBM depends on the value of MPCR compared to the total number of players, N, and the number of players per group, n. Equation 2.5 shows the condition under which the NEE exists:

$$\text{MPCR} \geq \frac{N - n + 1}{Nn - n^2 + 1} \tag{2.5}$$

The NEE is an asymmetric equilibrium where all players contribute all their endowments w each round except for a $z < n$ number of players who free ride and contribute nothing. Gunnthorsdottir et al. (2010a) find that the number of free riders, z, depends on the MPCR, denoted briefly as m, the total number of players, N, and the number of players in each group, n, as shown in equation 2.6.

$$z = \left\lceil \frac{N - mN}{mN - mn + 1 - m} \right\rceil \tag{2.6}$$

[9] Theorists commonly assume that players prefer pure strategies if they are available (see e.g. Kreps, 1990, p. 407-410; Aumann, 1985, p. 19). Mixed strategies are cognitively more difficult and require randomization that humans are generally not considered good at (Wagenaar, 1972).

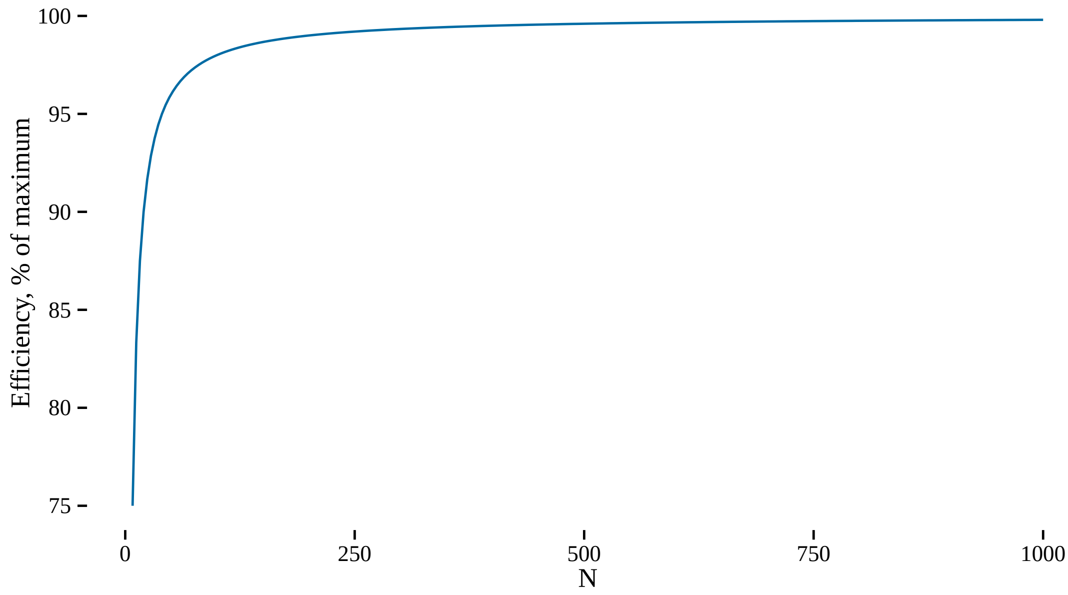

Figure 2.1: Efficiency in the near efficient equilibrium for all N in the range of 8 *to* 1.000 *and fully divisible by* 4 *with a group size of* $n = 4$ *and MPCR* $= 0.5$.

As the number of groups of fixed size n grows, and with it the number of players N, the NEE asymptotically approaches full efficiency[10], see figure 2.1. Measured by the rate of cooperation, the NEE is clearly much more efficient than the NBA which by definition is the least efficient possible outcome. Since players share the gains of cooperation, more efficiency means that players receive higher payoffs.

Even though a Nash equilibrium may not be an infallible predictor of an outcome of a game, it is the typical approach of theoretical derivations. In cases where games do not contain a unique Nash equilibrium, predicting an outcome becomes more complex as additional criteria are needed to determine which one will ensue. These criteria are commonly known as *refinements* and are derived from principles of rationality (Ochs, 1998). The basis for such criteria can for example be desirability, likelihood or stability of the equilibria. Harsanyi and Selten (1988, p. 81) proposed the *payoff dominance* criterion which states that, given multiple equilibria, players should commonly prefer and coordinate on the equilibrium yielding the highest payoffs for each and every player. By applying the payoff dominance criterion, one would predict the NEE to be the outcome of the game.

While the NEE yields higher expected earnings for each player it does entail strategic risk as the additional earnings for a contributing player depend on other players contributing as well. Contributing nothing is a more secure alternative but the NEE however gives higher expected earnings for each and every player which might compensate for the risk. In general, if other player's deviations may be expected, such

[10]For more details see Appendix A of Gunnthorsdottir et al., 2010a.

as if credible commitments to the strategy leading to the payoff dominant solution are missing, players may opt for a different strategy. In such cases players may rather choose a *risk-dominant* (Harsanyi and Selten, 1988) solution that provides a higher payoff given the subjective probabilities the players have of other player's choices. Alternatively, factors such as focal points (Schelling, 1980)[11] or psychological prominence, salience, learning, cultural norms, etc., can affect which equilibria will be realized. Payoff dominance alone is therefore not a sufficient condition for solving a selection problem. Since players' perception of risk and the effects of psychological factors are hard to predict beforehand, payoff dominance remains as basis for an a priori hypothesis.

In reality, payoff dominance is not an impeccable predictor. Classic examples of its misguidance are the results of Van Huyck et al. (1990, 1991) who empirically tested so-called order-statistic games with multiple symmetric Pareto rankable equilibria and found that subjects failed to coordinate on the payoff-dominant one, opting to minimize strategic risk instead. Complexity of the game does not seem to be a factor. In a much simpler game, Cooper et al. 1990 also observed failure to coordinate on a payoff-dominant equilibrium despite players only having three distinct strategies. In fact there are numerous cases where its predictions have failed in similar experimental settings (see e.g. Devetag and Ortmann, 2007, for an overview).

Facing a social dilemma, subjects in a GBM have to choose between a safe choice of not contributing anything and a more profitable albeit somewhat riskier choice of cooperation. Theory does not give a definite answer to which one subjects will prefer. Despite historical evidence of prediction failure, payoff dominance is the prominent criterion for solving the equilibrium selection problem, leaving the NEE as the a priori predicted outcome.

Prior experimental tests of the GBM

As discussed above, the NEE is the theoretically predicted outcome of the GBM. In order for the NEE to be realized however, subjects need to coordinate their behavior tacitly along two different dimensions. First, subjects must decide collectively, but without communication, that they will play a higher-risk, non-obvious equilibrium. Note that no player can single-handedly instigate a NEE, it can only form out of a joint effort. Secondly, as the NEE is an asymmetric equilibrium, subjects must coordinate simultaneously on which player follows what strategy. This dual coordination requirement puts high demand on subjects' coordination abilities. Surprisingly, experimental results show that subjects do in fact coordinate on the NEE despite its complexity.

In Gunnthorsdottir et al. (2010a) the GBM was experimentally tested with US undergraduate students. Every session included $N = 12$ subjects, each endowed with 100 experimental tokens per round. Group size was set at $n = 4$ and the public account multiplier was set at $g = 2$ yielding a MPCR = 0.5. Each experimental

[11] A payoff-dominant equilibrium is of course a type of focal point.

session lasted for 80 rounds. During the experiment, the students successfully, accurately and consistently coordinated the NEE, without communicating and even in the very first trials. See Section 4 for more detailed description of the results.

While subject behavior would on aggregate follow the NEE prediction, many individual subjects varied their choices between rounds instead of following a strict strategy of either contributing nothing or fully. Charts depicting individual choice paths (see Appendix C) demonstrate that many subjects oscillate their behavior erratically between the free-riding action and the contributing action.

How a group of symmetric subjects are able to coordinate an asymmetric equilibrium on aggregate by acting unsystematically and without communicating is still a mystery. Such behavior has been observed before in *market entry games* and was famously described by Kahneman (1988, p. 12) as “magic” (for overviews see Ochs 1995, 1998; Camerer and Fehr 2006). Still, market entry games are substantially simpler with only a binary strategy space and an obvious equilibrium.

While the results of Gunnthorsdottir et al. (2010a) reveal a remarkable capability of subjects to coordinate the complex and asymmetric NEE, the subjects were all US students. The question thus remains whether the predictive power of the NEE holds in different cultures or if it is specific to the US. Section 4 will reveal whether subjects in a different culture are capable of dealing with the GBM’s demanding coordination requirements. Performing additional experimental tests of the GBM also serves a purpose of increasing the validity of former results.

3. Experimental method

Experiments were conducted at the University of Iceland in the spring of 2011 in order to collect data for the two distinct studies of this thesis; the replication of Gunnthorsdottir et al. (2010a) in Section 4 and the extended model, a version of the GBM, described in Section 5. There were two experimental conditions; a *homogeneous endowment* condition and a *heterogeneous endowment* condition respectively. The distinction between the two conditions is described below. In order to maintain comparability with earlier studies, parameters and methods were chosen to be the same or as close as possible to ones used in the earlier studies. This chapter describes the procedures and parameters used in both treatments. For more detailed information on the experimental procedures see Appendix A. Chapter 4 contains a comparison with data previously collected at George Mason University in the United States. Data collection methods were identical. For further details see Gunnthorsdottir et al. (2010a).

3.1. Recruiting and experiment parameters

Subjects were recruited from the general student population of the University of Iceland. A total of eight experiments, four of each condition, were conducted in a computer lab at the University of Iceland in April and May 2011. The computer lab was specially equipped with blinders between computers making it suitable for experiments.

The same set of experimental protocols were used for each of the eight sessions and the instructions were the same, apart from the sections where the endowment levels are described which were adjusted for each condition. The wording of the instructions was practically the same, although slightly more detailed, as in the instructions used when collecting the US data for Gunnthorsdottir et al. (2010a). In all sessions there were $N = 12$ subjects and 80 rounds of decision making. Group size was set at $n = 4$ meaning that subjects were divided into $G = 3$ groups according to the grouping mechanism of the GBM (see below). The public account was multiplied by $g = 2$ and the private account by $p = 1$. Since the MPCR was equal to $g/n = 0.5$ the game qualified as a *social dilemma game*.

In the four sessions of the *homogeneous endowment* condition the subjects all received a 100 experimental token endowment per round to divide between the private and public accounts. In the four sessions for the *heterogeneous endowment* condition there were eight subjects endowed with 80 tokens and four with 120 tokens per round resulting in an average of 93.3 tokens[1]. The average number of tokens was thus slightly lower in the *heterogeneous endowment* condition[2].

Subjects were paid in cash for their participation based on the amount of tokens they earned during the experiment. The total token earnings for each subject was the sum of each round's earnings. The payment protocol was hence *all decisions paid* (ADP). The exchange rate between an experimental token and real life currency was decided at 0.17 ISK per experimental token. This exchange rate would give subjects an average total amount of $2,500$ ISK or 22 USD[3] for playing the predicted NEE in the *homogeneous endowment* condition. Additionally, subjects were paid a show-up fee of 700 ISK or about 6.2 USD.

3.2. Group assignment and information feedback

Once all subjects had made their contribution decision in a given round, the experimental software assigned the subjects to groups based on their contribution to the public good. The software first ordered all the subjects by their level of contribution, then grouped the four highest contributors together in the first group, subjects with contributions ranking 5th to 8th in the second group and subjects with contributions ranking 9th to 12th in the third group. Ties were broken at random. Once group membership had been established the software would calculate the earnings for each subject.

After each round a message was displayed where subjects were informed what the contribution of all subjects had been in that round. The contributions were displayed in the order in which the software had ranked them and partitioned into the three groups in which the software had accordingly allocated each subject. This allowed the subjects to monitor how they were grouped after each round and what the contributions of their group members had been. This also allowed the subjects to correlate their group allocation with their contribution decision each round which facilitated learning. As subjects had been informed in the beginning that all ties would be broken at random the information given between rounds was an important factor in establishing the notion that the system was fair.

[1] In Gunnthorsdottir et al. (2010b), where heterogeneous endowment levels in the GBM had previously been studied, there were six subjects in each endowment class with either 80 or 120 tokens resulting in an average endowment of 100 tokens.

[2] The lower average endowment in the heterogeneous endowment condition causes the mean contributions per round for all subjects to not be comparable with the mean contributions per round in other conditions, i.e. Gunnthorsdottir et al. (2010b,a) or the data collected for the homogeneous endowment condition. In order to maintain an average of 100 tokens the high endowed subjects could have been given 140 tokens or the low endowed 90 tokens.

[3] The experiments ran from April to May 2011. The average exchange rate for that time period was 1 USD = 113.7 ISK.

4. A cross cultural comparison of homogeneous endowments[1]

The Group-based Meritocracy Mechanism (GBM) was originally conceived by Gunnthorsdottir et al. (2010a) as a method to model contribution-based grouping in a public goods game. Gunnthorsdottir et al. tested the GBM experimentally using US university students and found that subjects, without communication, reliably coordinated a near efficient equilibrium (NEE) - a complex, non-obvious Nash equilibrium requiring a great deal of simultaneous coordination between subjects. The fact that the subjects coordinated this equilibrium without communicating and any apparent learning is hence in many ways surprising. The question however still remains if the results were in some way dependent upon cultural factors of the US and if they might hold under an alternative culture. Were the results an observation of a phenomena isolated to the US or were the results general and independent from cultural factors?

The experimental subjects of choice – or, rather convenience, have often been US university students. In order to increase the external validity of conclusions drawn from experiments, it is highly desirable to expand the subject pool. A small but growing literature addresses how culture or demographics impact interactive decision-making. The evidence is somewhat mixed: Experimental markets often lead to similar results internationally (See, e.g., Beaulier et al., 2004), but other games show noticeable variation; see, e.g., the classical early study by Roth et al. (1991) with *ultimatum games* (UG). Differences in UG behavior become more pronounced the more cultures differ; see for example Henrich et al. (2001). Henrich et al. also cross-culturally test standard social dilemma games (of which the GBM is an extension) and find significant behavioral variation across distinct and diverse cultures. I am not aware of any work testing "magic" cross-culturally.

Since the literature suggests that culture might be an influential factor in experiments, doing a cross cultural comparison of the GBM serves the purpose of revealing cultural variations in the mechanism and to check if subjects from the comparison country behave differently when fronted with the choices presented by it. Culture might therefore possibly impact which of the two GBM equilibria subjects select. However, aside from equilibrium refinements such as payoff dominance, there is no a priori hypothesis to go by.

This chapter compares results of GBM experiments conducted at the University

[1] This chapter has previously been published in the MODSIM2011 conference proceedings. See Gunnthorsdottir and Thorsteinsson (2011).

of Iceland in 2011 with the US data set from Gunnthorsdottir et al. (2010a) collected at George Mason University.

4.1. Cultural differences

The two countries where the data sets are drawn from, the US and Iceland, are both developed economies and established democracies. They differ however along important dimensions including geography, demographics, economic structure, and hence, culture. In Iceland, a geographically isolated island nation, production is concentrated on a few sectors and its population of about 300,000 is highly homogeneous. The US has a population about 1,000 times larger, and is ethnically, culturally and economically diverse.

A Highly Individualistic, Masculine Society versus a Moderately Individualistic Feminine Society

Hofstede's dimensions of culture (Hofstede, 2001) are frequently applied measures of cultural differences between nations. Typically, Hofstede measures cultures on five different scales; Power Distance, Uncertainty Avoidance, Individualism, Masculinity, and Long-Term Orientation. Figure 4.1 compares the two countries on the four scales for which data was available for both countries.[2] The scale in which the two countries differ most is Masculinity. The Hofstede scale depicts the US as a highly "Masculine" culture, with a score of 61, while Iceland's culture, with a score of 10, is considered "Feminine". Masculine culture is among other things ego- and money-oriented, assertive and competitive while a feminine culture emphasizes caring (Hofstede, 2001, p. 297). High Masculinity might lead US subjects to vigorously compete for membership in high-contributing groups. The two countries also differ markedly on the Individualism scale, that is, the degree to which citizens are integrated in groups, have close bonds with each other, and rely on each other. According to the Hofstede data the US are the most individualistic nation world-wide with a score of 91, while Iceland is estimated much lower, at 60, even though still above the world mean of 43 (itim International, 2011).

A Meritocratic versus a Kinship-oriented Culture

According to the World Value survey the countries score similarly in interpersonal trust. Both rank just slightly above the world average, with Iceland scoring only marginally higher than the US (Morrone et al., 2009). Kinship clusters and other close personal or political ties strongly impact economic decisions in Iceland, including hiring or inter-firm interaction (Kristinsson, 2006; Baldvinsdóttir, 1998). Compare this to the US with its nationally mobile work force and distinctly market-based exchange and hiring.[3] Not surprisingly then, while both countries are meritocratic

[2] In absence of direct Icelandic data, I use estimates used by *itim International consultancy* and provided by G.J. Hofstede via personal communication, 2. July 2011.

[3] Despite the importance of personal ties in its economy, Iceland ranks as the seventh least corrupt country in the world on the Corruption Perception Index , while the US ranks 18th (Zinnbauer

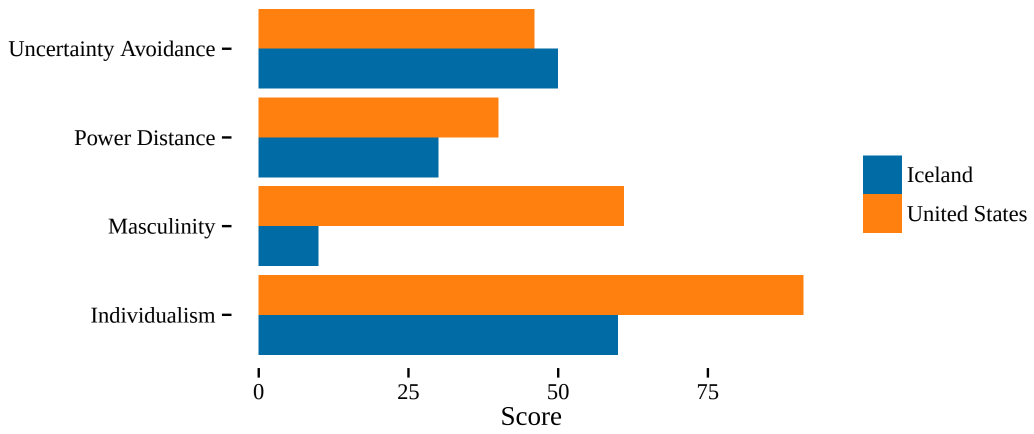

Figure 4.1: A comparison between Iceland and the US on Hofstede's dimensions of culture.

on a world–wide scale, Iceland ranks behind the US (Marks, 2010). Since the GBM is a simple model of meritocracy and since precedents impact equilibrium selection, again, one might expect US subjects to respond more readily to the NEE's meritocratic incentives.

4.2. Experimental design and parameters

The US data was collected at George Mason University in 2005 while the Icelandic data was collected at the University of Iceland in 2011. In both locations there were a total of 48 participants recruited from the student population and in both locations the same parameters, experimental protocol and software were used. While the instructions were in English in both locations and essentially the same, their wording differed slightly being a little more precise in Iceland. The instructions for each location can be found in Appendix E.

At each location, four sessions were held with $N = 12$ subjects for 80 rounds. Subjects were paid a show-up fee of 7 USD in the US and 700 ISK[4] in Iceland. Subjects were further rewarded for each earned experimental token. The exchange rate for the US subjects was $1,000$ tokens per 1 USD except for a single session where the exchange rate was 880 tokens per 1 USD[5]. For the Icelandic subjects the exchange rate was 5.9 tokens per 1 ISK. For further information on how the data for this thesis was collected see Chapter 3. For a more detailed overview of how the US data was collected see Gunnthorsdottir et al. (2010a), particularly pages 989-990.

and Dobson, 2009).

[4] At the time the Icelandic experiments were conducted the exchange rate was about 1 USD = 113.7 ISK.

[5] The data for the single session with the exchange rate of 880 tokens per 1 USD did not differ from the other sessions.

The parameters for each session were the same. Each subject was endowed with $w = 100$ tokens per round to invest in either a public account or a private account. In each session $N = 12$ participants were divided into three groups of $n = 4$ subjects. Group allocation was determined anew each round depending on subjects' contribution to the public account (i.e. the public good). Each round a group account was defined for each group with the total public account contributions from each group member. The group account was multiplied by $g = 2$ and evenly split between group members. In each session the marginal per capita return (MPCR) is therefore the same and equal to $g/n = 0.5$.

4.2.1. The NEE for the experimental parameters

We begin by verifying that the NEE exists for the parameters in question. By inserting the parameters above into equation 2.5 one can verify that this condition holds for the current experimental parameters[6].

In an NEE there are z number of subjects who contribute nothing while the remaining $N - z$ subjects will contribute fully or all of their endowments. We use equation 2.6 to determine the number of free riders z. Note that the MPCR is denoted here briefly as m.

$$\begin{aligned} z &= \left\lceil \frac{N - m \times N}{m \times N - mn + 1 - m} \right\rceil \\ &= \left\lceil \frac{12 - 0.5 \times 12}{0.5 \times 12 - 0.5 \times 4 + 1 - 0.5} \right\rceil \\ &= 2 \end{aligned}$$

Knowing that two out of twelve subjects should contribute nothing we can calculate the average contribution and expected payoffs. With the remaining $N - z = 10$ subjects contributing fully, the estimated mean contribution is $E(\bar{x}) = 83.3$ tokens per round[7]. Given the chosen parameter of MPCR = 0.5, a non-contributing subjects' expected NEE earnings is 200 tokens. A contributing subject will expect slightly lower earnings or 180 tokens per round[8].

Let's define the two sets $a^A_{-i} = (0, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100)$ and $a^B_{-i} = (0, 0, 100, 100, 100, 100, 100, 100, 100, 100, 100)$ as action profiles for all subjects N apart from subject i when playing NEE strategies. We can verify that contributing nothing is a unique payoff-maximizing best-response for subject i given a^A_{-i} while contributing 100 tokens is a best-response given a^B_{-i}. The payoff functions for player i given the two sets, $\pi_i(a_i, a^A_{-i})$ and $\pi_i(a_i, a^B_{-i})$, are depicted in figure 4.2. Since in S_{NEE} all subjects N face either a^A_{-i} or a^B_{-i}, we can conclude that all subjects N are in fact playing their best-response and that S_{NEE} is a Nash equilibrium.

[6] The parameters state that MPCR = 0.5 and that $\frac{N-n+1}{Nn-n^2+1} \approx 0.273$.

[7] More specifically, the estimated mean contribution is $E(\bar{x}) = \frac{2\times 0+10\times 100}{12}$.

[8] One can verify that with a larger N the earnings of contributors approach the earnings of non-contributors, in this case 200 tokens.

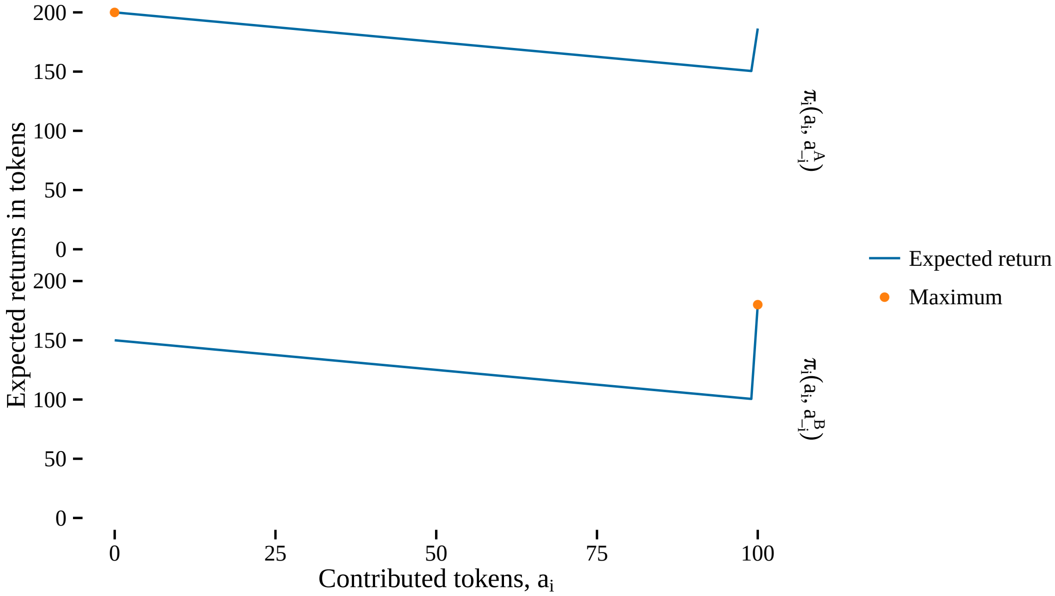

Figure 4.2: The payoff functions for a player i in a GBM who faces two different action profiles a_{-i}^{A} and a_{-i}^{B} from S_{NEE}, i.e. when all other players play NEE strategies.

4.2.2. Equilibrium selection

As discussed in Section 2.2, the GBMs two pure strategy equilibria[9] are *no contribution by all* (NBA) and the *near efficient equilibrium* (NEE). The action profiles for each are henceforth depicted by a^{NBA} and a^{NEE} respectively. Section 2.2 further demonstrated how the NBA equilibrium always exists in the GBM given that $p > \mathrm{MPCR} > 1/n$ holds while Section 4.2.1 proved the existence of a NEE in the GBM given the current parameters.

Table 4.1 shows the action profiles (subject choices) for the two Nash equilibria as well as the efficiency[10] of each equilibrium. The average expected earnings for all subjects in an NBA equilibrium is 100 tokens while expected earnings would be 200 and 180 respectively for the free-riding and contributing subjects in an NEE. The expected earnings are considerably higher in an NEE than in an NBA equilibrium. Applying the payoff dominance criterion (Harsanyi and Selten, 1988) the NEE should be mutually favored by subjects over the NBA equilibrium. Given that payoff dominance holds, players should coordinate on the NEE.

[9] Section 2.2 explains additional pure strategy equilibria in the very close vicinity of the NBA. These are empirically indistinguishable from the NBA and therefore excluded here.

[10] Following Gunnthorsdottir et al. (2010a) the efficiency is measured as $\sum_{i=1}^{N} s_i/Nw$.

Table 4.1: Action profiles known to be Nash equilibria for the case of $N = 12$ subjects endowed with $w = 100$ tokens and a group size $n = 4$.

	Actions	Efficiency %
ACTION PROFILE		
a^{NBA}	$(0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)$	0.0
a^{NEE}	$(0, 0, 100, 100, 100, 100, 100, 100, 100, 100, 100, 100)$	83.3

4.3. Empirical results

The experimental data from both the Icelandic and the US sessions was analyzed on two different dimensions in order to see if subjects played the NEE; the *mean contribution per round* and the *distribution of strategy choices*. The results for both countries was then compared in order to test for possible culturally based differences. The analysis yielded four main observations.

Observation 4.1. The NEE predicts aggregate behavior in both cultures

Figure 4.3 shows the mean subject contribution per round, separately for each country. The expected NEE predicted mean contribution per round, $E(\bar{x}) = 83.3$ tokens, is also charted on figure 4.3. Figure 4.3 indicates that both Icelandic and US subjects closely follow the NEE mean. The average contribution by the US students was 83.7 tokens per round and 79.6 by the Icelandic students. Even though the NEE is unlikely to be obvious to subjects, the vicinity of the NEE mean was reached very quickly in both countries. Icelandic subjects contributed on average 78.56 tokens out of 100 already in Round 3 and 81.94 tokens in Round 4 while US subjects contributed 77.81 in Round 2 and 88.94 in Round 3.

Observation 4.2. The frequencies with which strategies were chosen correspond to the NEE frequencies

Figure 4.4 shows the frequencies of observed strategies by country. Bullets represent the NEE predicted proportions. Subjects clearly favor the NEE strategies as observed frequencies are very close to NEE predictions in both countries. Again, the US data are slightly more precise.

Observation 4.3. A barely noticeable learning trajectory in Iceland and no apparent learning in the US

Icelandic subjects exhibited a slight learning process as they increased their precision over subsequent rounds. Their mean contribution over 80 rounds and four sessions is 79.61 tokens; the corresponding US value is 83.74, essentially exactly the NEE mean. A Mann-Whitney-Wilcoxon test (see, e.g., Siegel and Castellan,

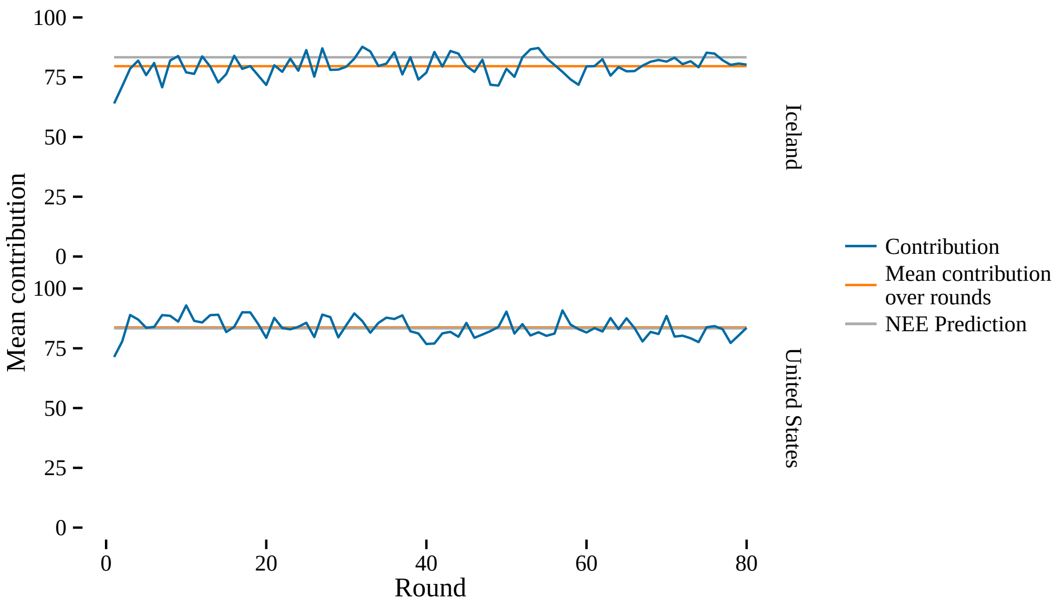

Figure 4.3: Mean contribution per round in each country.

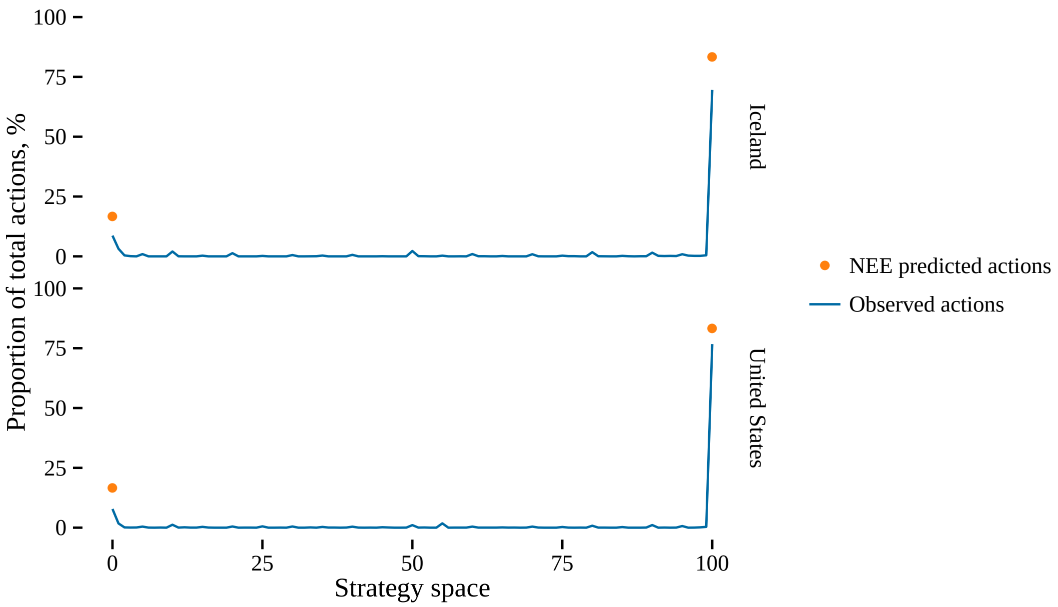

Figure 4.4: Strategy choices over four sessions and 80 rounds.

1988) with the session mean as the unit of analysis indicates that this slight difference is systematic (Mann-Whitney $U = 10$, $n = m = 4$, $p[2 - tailed] < .03$). However, the difference gradually disappears over rounds: When session means are based on Rounds $21 - 80$ only, one can no longer reject the null hypothesis that the session means are drawn form the same population (Mann-Whitney $U = 13, p[2 - tailed] < .2$). In the last 20 rounds the Icelandic overall mean is 81 and the US overall mean is 82. Both countries, in spite of their cultural differences, clearly coordinate the NEE rather than the inefficient equilibrium. However, while Icelandic students are used to reading English, it is not their native language. Gunnthorsdottir (2009) suggests that the precision with which the NEE is coordinated is, sensitive to subjects' knowledge of the rules of the game.

Observation 4.4. Individual decision paths are unsystematic

While in the aggregate subjects follow the NEE closely the same cannot be said for individual subjects[11]. In both countries, many players oscillate unpredictably between the two NEE strategies of contribution and non-contribution. While individual decision paths exhibit seemingly erratic oscillations, the aggregate paths (figure 4.3) remain quite smooth. This can only occur if individual oscillations offset each other. A similar pattern, denominated as "magic", has also been observed in market entry games (see e.g. Kahneman, 1988, Camerer, 2003, ch. 7.3).

4.4. Conclusion

This chapter examined the robustness of the GBM mechanism by comparing data that was collected in experiments in two different countries with dissimilar cultures. Parameters were chosen so that a NEE, a payoff dominant, asymmetric and complex equilibrium, would exist. In each cultural setting, the NEE was predicted *a priori* to be coordinated by the subjects. However, since the NEE is both complex and requires tacit coordination among players, it was by no means obvious that subjects would coordinate it. Indicators of variations between the two cultures suggested that the Icelandic subjects might be less successful at coordinating the NEE than US subjects. The data however indicate that subjects from both countries possess striking ability to tacitly coordinate complex Nash equilibria.

Following are the two main conclusions of this chapter:

Conclusion 4.1. The NEE is a robust predictor of aggregate behavior in a GBM

The surprising ability of subjects in a GBM mechanism to coordinate the NEE is a robust occurrence. Subjects in different countries, with different cultures and even with slightly differently worded instructions, produce identical aggregate patterns of behavior via simultaneous decisions, without communication and without a significant learning trajectory.

[11]Graphs of individual choice paths can be found in Appendix C.

Conclusion 4.2. Typical game theoretical behavioral premises apply to Icelandic subjects

In order for subjects to tacitly coordinate the NEE in a GBM mechanism, the subjects must demonstrate behavior based on typical game theoretical premises. The fact that Icelandic subjects successfully coordinated the NEE show that these premises apply to Icelandic subjects in a similar measure as with US subjects. The results indicate that the Nash equilibrium is an organizing principle for the aggregate behavior of Icelandic subjects as well. The Icelandic subjects coordinated the efficient and payoff dominant NEE instead of the inefficient NBA equilibrium, indicating that the payoff dominance criterion may act as a predictor for Icelandic subjects when given multiple Pareto rankable equilibria. Finally, the results demonstrate Icelandic subjects' ability to "magically" coordinate an asymmetric equilibrium tacitly.

4.4.1. Discussion

As outlined in Section 4.1, Iceland and the US differ on important cultural and social dimensions. However, both are democratic and affluent Western societies. Gunnthorsdottir et al. (2010b) suggest that the GBM could serve as a simple formal model of meritocratic social grouping. While the US is more meritocratic than Iceland (see Section 4.1), the countries are somewhat close to each other on this dimension. Further, subjects in both locations were university students used to some merit-based selection. Real-life precedents may thus have helped these subjects coordinate the NEE rather than the alternative inefficient equilibrium. The next step is to test the robustness of the findings here with different demographic groups, in developing countries or native communities, and in communities where social organization is less meritocratic and more privilege-based.

5. Heterogeneous endowments and society composition effects

In the original Group-based Meritocracy Mechanism (GBM) experiments of Gunnthorsdottir et al. (2010a), as well as in the experiments described in Section 4, the subjects have homogeneous endowment levels. One way of interpreting subject endowment levels in public good games is as the subject's ability to contribute to a public good. Given such interpretation, homogeneous endowment levels would be an assumption that all subjects have the same ability to contribute to society. However, in naturally occurring circumstances people's abilities differ, often by a large margin. The question arises whether different abilities, measured by the level of endowment, affect subjects' decisions to contribute to a public good and if so in what way.

The effects of different endowment levels in the GBM were first addressed by Gunnthorsdottir et al. (2010b) where the twelve subjects within a given session were divided into two equally sized but differently endowed groups or *endowment classes*. While the six subjects of the first endowment class, the *lows*, were given 80 tokens per round the six subjects of the second endowment class, the *highs*, were given 120 tokens. In total over both groups the mean endowment was 100 experimental tokens per round, the same as in Gunnthorsdottir et al. (2010a) meaning that the collective abilities of the subjects to contribute to the public good was exactly the same. Apart from the endowment distribution, all parameters and characteristics were the same as in earlier GBMs, (see Section 2.2) including competitive grouping of subjects based on their contribution level and random breaking of ties. Gunnthorsdottir et al. (2010a) show that, with the altered endowment distribution, a NEE still exists where a z number of low endowed players contribute nothing while all other players, high and low endowed, contribute fully. This NEE was realized with experimental subjects.

Gunnthorsdottir et al. (2010b) show that the total level of efficiency, measured as the sum of subjects' earnings, can be greater when subject endowment levels are heterogeneous than when endowments are equal as in the original GBM. In fact Gunnthorsdottir et al. (2010b) find that the efficiency increased with the difference in endowment levels. Inequality thus, perhaps paradoxically, increased the welfare of the subjects - both individually and as a group. The highly efficient NEE of Gunnthorsdottir et al. (2010b) is however dependent upon the fact that group size did not coincide with the number of subjects of each endowment class. The number of subjects of each endowment class versus the number of subjects in each group forced mixed grouping of player classes in at least one out of three groups. By raising their contribution levels, the higher endowed subjects would compete for placement in the top level group with the highest returns and try to avoid involvement with the mixed group. At the same time, the lower endowed subjects would compete for placement in the mixed group where they could benefit from the higher contributions of the high endowed subjects. Consequently, both player classes had incentives to compete internally for group placement by raising contribution levels.

In Gunnthorsdottir et al. (2010b), the incentive for raised contributions was brought on by the existence of the mixed group and the will to either join it or avoid it. This leads us to the question: what if we adjust the number of subjects of each endowment class relative to the number of groups so that there is no mixed group of subjects? Will that affect the contribution decisions? In this chapter we will explore what happens if we alter the game so that a mixed group of subjects with different endowments is no longer required to emerge.

5.1. A model with heterogeneous subjects

We now alter the typical GBM model so that all N players get separated into two or more endowment classes $\mathcal{C} := \{c_1, \ldots, c_k\}$ and for each endowment class c_i we have some player count τ_{c_i} (type count[1]) which is a positive integer such that $\tau < N$ and fully divisible by the group count n. Formally we write this *full divisibility condition* as

$$\tau \in \mathbb{N}^+ : \tau < N \text{ and } n \mid \tau \tag{5.1}$$

Furthermore, in each round all players within each endowment class receive a fixed amount of tokens w_{c_i} which is a positive integer and different from the amount of tokens given to every other endowment class.

The *full divisibility condition* enables the possibility of groups being assembled only by players belonging to a single endowment class. We will show that this consequence has several implications for the Nash equilibria of the game. While the model does not enforce homogeneously assembled groups, we will show that such grouping of players will occur in a Nash equilibrium with positive contributions.

In Gunnthorsdottir et al. (2010b), members of the class with the higher endowment had to compete for placement in a higher tier group due to the possibility of being grouped with lower endowed players. The current model's absence of forced mixed grouping however means that as long as all members of a higher endowed class raise their contributions only an ϵ above the endowment of the next lower level class the probability of being grouped by the lower caste diminishes. If all members of one class follow this strategy they stay together with 100% probability. Now, the fear of being grouped with lower endowed players no longer drives the higher endowed to compete among themselves as was the case in Gunnthorsdottir et al. (2010b). Unless the higher endowed players compete for placement in an even higher group, they have no incentive to raise their contribution above the minimum necessary to stay

[1] The type count is the number of players belonging to that particular endowment class.

above the lower group. However, if there is competition for placement in a higher level group, the logic will repeat itself; players with even higher endowments will surpass the next lower level in their contribution, but still only the bare minimum necessary - unless there is again competition for group placement.

5.1.1. A society of societies

When the members of a lower endowed class no longer get grouped with members of higher endowed classes, the members of the lower endowed class and those higher endowed who surpassed them effectively form separate *social strata*. As long as all higher endowed players contribute an ϵ more than the lower endowed are capable of, the decisions of higher endowed players no longer concern the lower endowed ones. In contrast, the decisions of the lower class still concern the higher ones: it can be verified that in all cases it does not behoove a higher class member to be grouped with a lower class if he or she can avoid it by contributing an ϵ more than the highest contributing lower class member. However, if no lower endowed player contributes her full endowment a higher endowed player can reduce her contribution to that contribution plus ϵ and still stay in the top tier, free riding in a way off her fellow class members who still contribute the earlier amount. Once free riding starts in a particular social stratum, other players may start to free ride as well, culminating in the stack of social strata crashing like a *Jenga* tower.

As the outcome of each social stratum is dependent upon the outcome of the next lower level one, one cannot predict what *type* of social stratum will form for any higher level one without knowing what members of a lower stratum will do. In order to make a prediction about what happens it is helpful to first picture the players of each endowment class as forming their own social stratum and then look at the type of social stratum that members of each endowment class are *capable* of forming independent of the other endowment classes. There are two factors that determine the outcome of each social stratum; a) the number of players within the stratum (type count) in proportion to the group size n and b) what here will be called the *class strategy space.*

Definition 5.1. Class strategy space. Let's define the *class strategy space* Δw_{c_i} as the strategy space of class c_i minus the strategy space of the next lower endowed class c_{i-1}, if any lower endowed class exists. By choosing a strategy from their *class strategy space,* players of a higher endowed class defeat any lower endowed players in a competition for group placement. Because membership in a higher tier group generally yields a greater return than any lower tier group,[2] players aspire to get to the highest level group they can. As long as there is competition for group membership at a lower level, the *class strategy space* must therefore contain the

[2]A notable exception to this is the return of free riders in the lowest group in a GBM when playing an NEE. Their returns may be slightly higher than for contributors in a higher tier group if N is small, see Section 2.2.

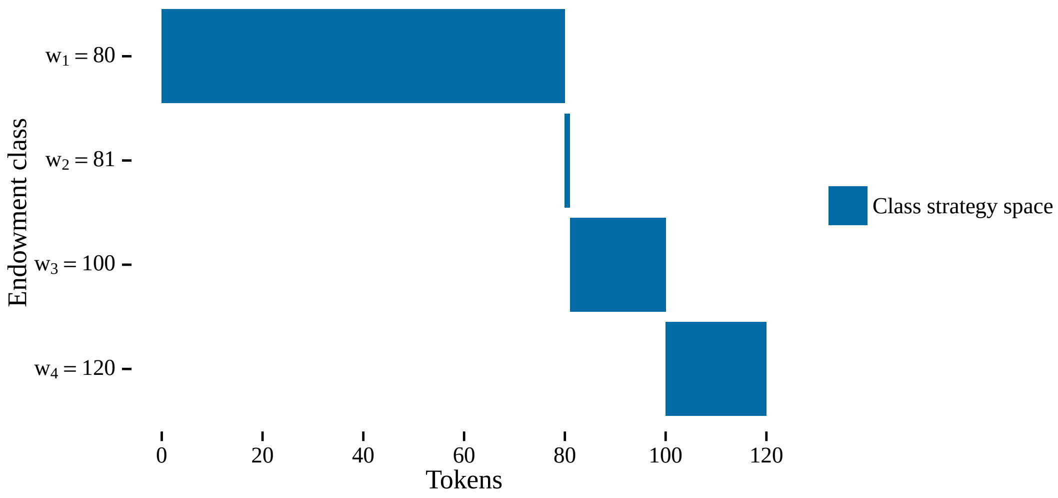

Figure 5.1: Class strategy spaces in case of three endowment classes; 80, 81, 100 and 120 tokens.

	$\lvert\Delta w_{c_i}\rvert > 1$	$\lvert\Delta w_{c_i}\rvert = 1$
$\tau_{c_i} = n$	VCM	Forced Cooperative
$\tau_{c_i} > n$ and $n \mid t_{c_i}$	GBM	

Figure 5.2: The possible types of social strata under the full divisibility condition.

best response strategy of members of that particular class[3]. In such a case, the *class strategy space* can be viewed as the effective strategy space of each endowment class.

For each endowment class c_i, the type count, τ_{c_i}, relative to group size, n, and the size of the *class strategy space* determine the nature of the social stratum that the players will form. Following are the types of social strata that can emerge if all players have positive endowments and each social stratum only contains members of a single endowment class[4]:

[3] More specifically, as will be discussed later, the best response is either the upper or lower bound of the *class strategy space*.

[4] This list may not be complete. Note that for example mixed strategies have not been considered. The endowments and type distributions in figure 5.2 should be considered examples for illustration only and without loss of generality.

5.1.1.1. The VCM social stratum

When the type count τ_{c_i} of an endowment class c_i equals the group size or $\tau_{c_i} = n$ and the class strategy space contains $|\Delta w_{c_i}| > 1$ strategies the social stratum will effectively become a VCM type social stratum. As the stratum only consists of one group of players, the players have no need to compete for group placement by raising their contribution above the minimum necessary to stay within the social stratum. In such a setting, the equilibrium effectively follows a traditional VCM albeit with a minimum contribution equal to the lower bound of the class strategy space.

While players are predicted to contribute only a bare minimum as in a traditional VCM there is an important distinction to be made. Assuming the existence of a lower level social stratum with positive contributions, the equilibrium contribution of the players of class c_i will be positive giving the appearance that they are cooperating, because, unlike in the VCM's NBA equilibrium, their contributions are positive. However, even though the positive contributions may have the appearance of a cooperative effort it is only sustained by individual players' desire to not mingle with a lower level class. The positive contributions are not explained by any intra-stratum mechanism such as cooperation or competition.

5.1.1.2. The forced cooperative

If the number of strategies in the class strategy space of class c_i is $|\Delta w_{c_i}| = 1$ then each player effectively has only one option which is to contribute the single amount in the class strategy space. The predicted equilibrium within a forced cooperative social stratum is simply the single feasible option or the full endowment w of the players belonging to the class c_i. In a forced cooperative, the type count τ_{c_i} relative to group size n is not a determining factor for the equilibrium outcome and a forced cooperative can span either one or multiple groups.

While a forced cooperative social stratum spanning a single group can be seen as a case of a VCM with a very small strategy space, a distinction must be made as these two social stratum types have different implications when combined into a larger mechanism. These implications will be further discussed in Section 5.1.2.2.

Recall that players always have the possibility to contribute nothing. The only case where a forced cooperative (i.e. a social stratum with $|\Delta w| = 1$) could possibly be at the very bottom rung of the stratified society is if their endowment is $w = 0$. Such a case would be trivial since players have no choice but to "contribute" 0.

5.1.1.3. The GBM social stratum

A GBM type social stratum emerges when the player count τ_{c_i} within the endowment class c_i is equal to at least twice the group size n and the class strategy space contains $|\Delta w_{c_i}| > 1$ strategies. When the members of an endowment class can be split into at least two groups, the *intergroup competition* aspect of the GBM is activated. The equilibrium analysis of a GBM social stratum follows the logic explained in Section 2.2 although with the player strategy space limited to the bounds of the class strategy space Δw_{c_i}. Applying the Payoff dominance criterion (Harsanyi and Selten, 1988), an NEE is predicted to emerge (see Section 2.2).

A notable aspect of the GBM social stratum is that there is intra-stratum competition for group membership resulting in positive and full contributions from a majority of the social stratum members.

5.1.2. Overall equilibrium analysis

The Nash equilibria of the GBM model, of which this extended model is a version, have been extensively explored by Gunnthorsdottir et al. (2010a). These equilibria are described in detail in Section 2.2. The two most plausible equilibria are the NBA equilibrium and the NEE which is specific to GBM games. Gunnthorsdottir et al. (2010b) show that in many cases where the endowment distribution is altered, the NEE still applies. They also show that the existence of the NEE despite the altered endowment distribution is dependent on the particular distribution chosen, specifically that the number of players belonging to each endowment class does not coincide with the number of players in each group. The fact that there is inevitably a mixed group of players encourages competition between members of different endowment classes for group membership and supports the emergence of the NEE across endowment classes.[5] As previously discussed, the current model as described above differs in that it does not force the emergence of a mixed group. As players can effectively avoid competition other endowment classes the rationale for a NEE across endowment classes no longer applies.

The analysis here uses a continuous strategy space and focuses on pure strategy equilibria. For the possibility of mixed strategy equilibria and the impact of the discretization of the strategy space into tokens see Gunnthorsdottir et al. (2010a); Gunnthorsdottir et al. show that subjects do not mix and that discretization only trivially changes a GBM's equilibrium.

5.1.2.1. Equilibrium 1: No contribution by all

As the model still represents public goods provision and extends the VCM and GBM models, the rationale for the existence of the *no contribution by all* equilibrium continues to apply as long as $p > \text{MPCR} > \frac{1}{n}$, in other words as long as the game is a social dilemma. The *no contribution by all* equilibrium will not be described here as it has already been covered in Section 2.1. Gunnthorsdottir et al. (2010b, section 3.4.1) however show mathematically that it still applies with two endowment levels.

[5]The possibility to mix with higher endowed players encouraged lower endowed players to contribute while the higher endowed players were unable to lower their contributions by ϵ as that would guarantee them being grouped with the lower endowed players where the returns were lower.

5.1.2.2. Equilibrium 2: The multi-tier equilibrium

The second known equilibrium is the *multi-tier equilibrium* (MTE), a variant of the NEE. It is not quite accurate to speak of the MTE as a single equilibrium as it is more like a family of one or more equilibria, all differing in efficiency, where the total number of possible MTE equilibria for a particular game configuration depends on the number of endowment classes. Furthermore, each multi-tier equilibrium is a combined equilibrium of multiple "smaller" sub-equilibria where the total group of players can be seen as forming two or more distinct *social strata*, each reaching their own equilibria that, when viewed together, form the whole multi-tier equilibrium. As listed in Section 5.1.1, the known possible types of social strata are the VCM, the forced cooperative and the GBM social stratum. Within each of these social stratum types a Nash equilibrium prediction has been provided. For a multi-tier equilibrium to be realized, in addition to the *full divisibility condition* (see equation 5.1) the following two conditions must be met:

Condition 5.1. The number of endowment classes $\mathcal{C}$ must be such that $|\mathcal{C}| > 1$.

This is obviously the case given heterogeneous endowments. As the members of each endowment class, τ_i, must at least be as many and fully divisible by the group size n, this is equal to stating that there must be at least two groups. With a single endowment class the game would be a standard GBM and with a single group we would have a VCM.

Condition 5.2. If the number of players τ of the lowest endowed class equals n then each member's strategy space can only contain one element, that is, the lowest endowed class must then form a forced cooperative type social stratum.

The reason for condition 5.2 will be discussed in more detail below.

As mentioned earlier, the outcome of each *social stratum* is dependent upon the outcome of the next lower level one. One cannot predict what kind of social stratum will form for any higher level social stratum without knowing what members of a lower social stratum will do. In order to derive the multi-tier equilibrium, one must first identify the different social strata that will form by grouping players together by their endowment class, then order them by their respective endowment level. Starting with the lowest endowed class, one finds the social stratum and respective Nash equilibrium prediction for each endowment class according to the class strategy space Δw and the type count relative to group size (see figure 5.2).

When each social stratum has been identified and its respective Nash equilibrium prediction found, one must again look through each social stratum, starting with the lowest level one. In case the current social stratum is either a GBM or a Forced cooperative, the stratum prediction can be confirmed and one can proceed to the next social stratum. However, in case the current social stratum is a VCM, every upper level stratum collapses and is combined with that VCM, forming one large VCM with a lower bound equal to the endowment of the last viewed endowment type plus ϵ.

Table 5.1: Examples of endowment type parameters and the type of social stratum they form.

Class, $\mathcal{C}$ / Endowment, w	Class strategy space Δw	Player count τ	Social stratum type
80	0...80	8	GBM
81	81	4	Forced Cooperative
100	82...100	8	GBM
120	101...120	4	VCM

In case the bottom ranked social stratum turns out to be a VCM, the lower bound of the collapsed social stratum will be equal to the minimum possible contribution.[6] As such an equilibrium is NBA and only contains one tier, it does not count as a multi-tier equilibrium. A requirement for the multi-tier equilibrium is therefore that the bottom stratum does not form a VCM stratum as ensured by condition 5.2. While player count and type count may be equal in a forced cooperative as in a VCM one might be tempted to think that no social stratum could be sustained atop of a forced cooperative as with a VCM. The crucial difference is that in a forced cooperative, players raise the "contribution bar" by selecting a strategy that is in the upper bounds of their class's strategy space[7], just like in a GBM, while in a VCM they play their lower bound strategy.

As an example, imagine a case of four different endowment types; $\mathcal{C} := \{80, 81, 100, 120\}$ and a type count of $\tau_{80} = 8$, $\tau_{81} = 4$, $\tau_{100} = 8$ and $\tau_{120} = 4$ respectively. Table 5.1 summarizes the configuration and respective social stratum for each endowment type. See figure 5.1 for a graphical illustration of the class strategy space. For this particular configuration there are at least[8] a total of three known multi-tier equilibria as well as the no contribution by all equilibrium.

For more examples of possible society configurations and the respective most efficient multi-tier equilibria, see Appendix B.

5.1.2.3. Equilibrium selection

Given that payoff dominance (Harsanyi and Selten, 1988) holds, players should agree on the most efficient equilibrium. Any equilibrium with positive contribution

[6] In a typical VCM game players are not forced to contribute anything and the minimum contribution is to contribute nothing.

[7] The single strategy in their class strategy space is their maximum contribution.

[8] Further analysis of all possible equilibria, in particular the impact of discretization of the strategy space and possible mixed strategy equilibria, is beyond the scope of this thesis.

Table 5.2: The action profiles known to be Nash equilibria for the example configuration in table 5.1.

ACTION PROFILE	Actions	Efficiency %
a^{NBA}	$\begin{pmatrix} 0,0,0,0,0,0,0,0,0,0,0,0, \\ 0,0,0,0,0,0,0,0,0,0,0,0 \end{pmatrix}$	0.0
a^{MTE1}	$\begin{pmatrix} 0,0,80,80,80,80,80,80,81,81,81,81, \\ 81,81,81,81,81,81,81,81,81,81,81,81 \end{pmatrix}$	79.1
a^{MTE2}	$\begin{pmatrix} 0,0,80,80,80,80,80,80,81,81,81,81, \\ 82,82,82,82,82,82,82,82,82,82,82,82 \end{pmatrix}$	79.7
a^{MTE3}	$\begin{pmatrix} 0,0,80,80,80,80,80,80,81,81,81,81,82,82, \\ 100,100,100,100,100,100,101,101,101,101 \end{pmatrix}$	87.9

by one or more players will by design be more efficient than an equilibrium of no contribution by all but not all subjects might prefer it or be better off this way than they would be in a NBA equilibrium. Of the known possible equilibria we can however generally assume that the most efficient *multi-tier equilibrium* will be mutually favored by the players and hence played.

5.2. Experimental design and parameters

As an empirical test for this modified, multi-level version of the GBM a series of experiments were conducted at the University of Iceland. A total of 48 subjects were recruited from the student population and divided into four experimental sessions. For further information on the recruitment process or the experimental procedures see Section 3. The parameters used were, for comparison purposes, the same as those used in earlier experiments (Gunnthorsdottir et al., 2010a,b). The total number of subjects in each session were $N = 12$ and were after each round divided into three groups of $n = 4$ subjects. The public account was multiplied by $g = 2$ resulting in a MPCR $= 0.5$.

The number of endowment classes and numbers of tokens for each class are as in Gunnthorsdottir et al. (2010b). The number of subjects within each class is however different. The subject pool was split into two endowment classes, *low endowed* and *high endowed* with the *low endowed* subjects endowed with an amount of $w_{\text{Low}} = 80$ experimental tokens per round and the *high endowed* with $w_{\text{High}} = 120$ tokens. While Gunnthorsdottir et al. (2010b) had equal number of subjects within each class, $\tau_{\text{Low}} = \tau_{\text{High}} = 6$, and not divisible with group size n the current experiment has a subject count that is different in each class, $\tau_{\text{Low}} = 8$ and $\tau_{\text{High}} = 4$, and fully divisible by group size n.

5.2.1. The MTE for the experimental parameters

In order to find the MTE we must first look at the lowest endowment class. The "lows" get 80 tokens per round. Being the lowest class their class strategy space is not bounded from below by any lower class. The class strategy space therefore ranges from 0 - 80 tokens resulting in a strategy space with a range of $|\Delta w_{\text{Low}}| = 81$ strategies. With $\tau_{\text{Low}} = 8$ class members and a group size of $n = 4$, $\tau_{\text{Low}} > n$ and $n \mid \tau_{\text{Low}}$. Using figure 5.2 we predict that the "lows" will form a GBM social stratum. Using equation 2.6 we can estimate the number of free-riders, using the number of class members τ_{Low} instead of total number of subjects, N such as:

$$\begin{aligned} z &= \left\lceil \frac{\tau_{\text{Low}} - m \times \tau_{\text{Low}}}{m \times \tau_{\text{Low}} - mn + 1 - m} \right\rceil \\ &= \left\lceil \frac{8 - 0.5 \times 8}{0.5 \times 8 - 0.5 \times 4 + 1 - 0.5} \right\rceil \\ &= 2 \end{aligned}$$

Using the number of free-riders $z = 2$, or the subjects contributing zero tokens per round, we can estimate the mean contribution of the lower endowed subjects. With two subjects contributing nothing and six contributing their full endowment of 80 tokens per round the estimated mean contribution is $E(\bar{x}) = 60$ tokens per round. Given a MPCR = 0.5 a free riding member of the lower class can expect a return of 160 tokens per round while a contributing member can expect to earn about 133.33 tokens.

The higher endowed subjects or the "highs" are endowed with 120 tokens per round. While the full strategy space of a high endowed subject ranges from 0 - 120, the class strategy space is bounded from below by the upper limit of the strategy space of the lower endowed or the "lows". The class strategy space therefore ranges from 81 - 120 with a number of strategies $|\Delta w_{\text{High}}| = 40$. The number of class members is $\tau_{\text{High}} = 4$ and equal to the group size n. Comparing these values to figure 5.2 we find that the "highs" will form a VCM social stratum where each member contributes the minimum amount of the class strategy space or 81 tokens per round. With an expected mean contribution of $E(\bar{x}) = 81$ and a MPCR = 0.5 each member of the higher endowed class has an expected return of 201 tokens per round.

An alternative way of thinking about the equilibrium would be to first assume that the subjects, independent of their endowment class, realize a NEE, the high endowed subjects can now make sure to be in the highest earning group by contributing a minimum of 81 tokens. Every strategy of 80 tokens or less would induce a risk of being grouped with the subjects in the group with the smallest payoff. Assuming this would be understood by all four "highs" they in turn form an "elite" group

Table 5.3: The strategy configurations known to be Nash equilibria for the case of eight subjects endowed with $w = 80$ tokens and four endowed with $w = 120$ tokens and group size of $n = 4$.

	Actions	Efficiency %
ACTION PROFILE		
a^{NBA}	$(0,0,0,0,0,0,0,0,0,0,0,0)$	0.0
a^{MTE}	$(0,0,80,80,80,80,80,80,81,81,81,81)$	62.8

of contributors. The “lows”, excluded from participation by their lower endowment levels, still play and benefit from the higher returns of the NEE. For the “highs”, a full contribution by all would yield the most efficient outcome. Still there is no incentive for any "high" to contribute more than 81 as for every individual player it is a best response to lower her contribution to 81 and free ride off of the over-contribution of others as in a typical VCM.

5.2.2. Equilibrium selection

Given the experimental parameters described in Section 5.2, two Nash equilibria are known; one multi-tier equilibrium (MTE) and the equilibrium of no contribution by all (NBA). Table 5.3 shows the efficiency for the two equilibria. The MTE is the more efficient equilibrium with 62.8% efficiency compared to zero or no measured efficiency in the no-contribution equilibrium. Each and every player is better off in the MTE and it is therefore preferred by everyone. We therefore predict the multi-tier equilibrium as the outcome of the game.

5.3. Empirical results

The empirical test of the model yielded five main results grouped into three different categories. The first category relates to the aggregate of all the subjects independent of endowment type while the following categories arrive from splitting the subject group by their respective endowment class. The logic for viewing each endowment level separately arises from the fact that while on the aggregate subjects play a multi-tier equilibrium, each endowment class is playing a separate game with their own separate equilibria.

5.3.1. Aggregate results

The estimated subject behavior for all endowment classes is represented by the multi-tier equilibrium. When observing subject behavior aggregated over all endowment

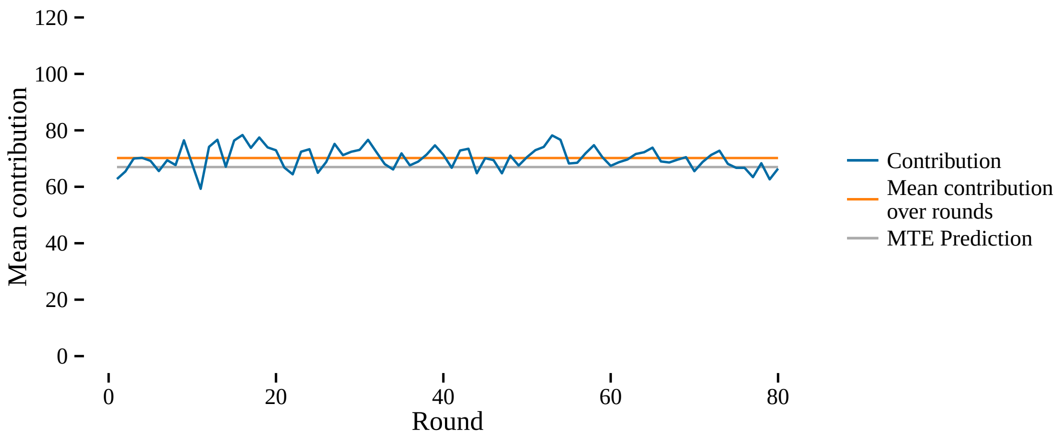

Figure 5.3: Mean contribution per round for all subjects in the heterogeneous condition.

classes there is one main observation:

Observation 5.1. Aggregated over all player types, round means correspond closely to predicted levels.

Given that subjects follow the multi-tier equilibrium the estimated mean contribution over all subjects, independent of endowment type, is $E(\bar{x}) = 67$ tokens per round[9]. The expected and observed mean contribution per round are compared in figure 5.3. For the experimental results, the mean contribution per round corresponds closely to the multi-tier equilibrium prediction with a mean over all rounds of $\bar{x} = 70.19$ tokens, an over-contribution of roughly 3 tokens per round on average.

5.3.2. Results for the lower endowed subjects

This section covers results from observing only the behavior of the low endowed subjects who were endowed with 80 tokens per round. The estimated behavior for the low endowed subjects is that they follow a NEE which they play among themselves.

Observation 5.2. The round means for "lows" correspond closely to predicted NEE levels

As explained in Section 5.1.2.2 the "lows" are effectively facing a GBM with a total of eight players and two groups. Out of the eight subjects endowed with 80 tokens per round, six were predicted to contribute fully and two to contribute nothing

[9]The expected mean contribution per round is derived in the following manner $\frac{2\times0+6\times80+4\times81}{2+6+4} = \frac{804}{12} = 67$.

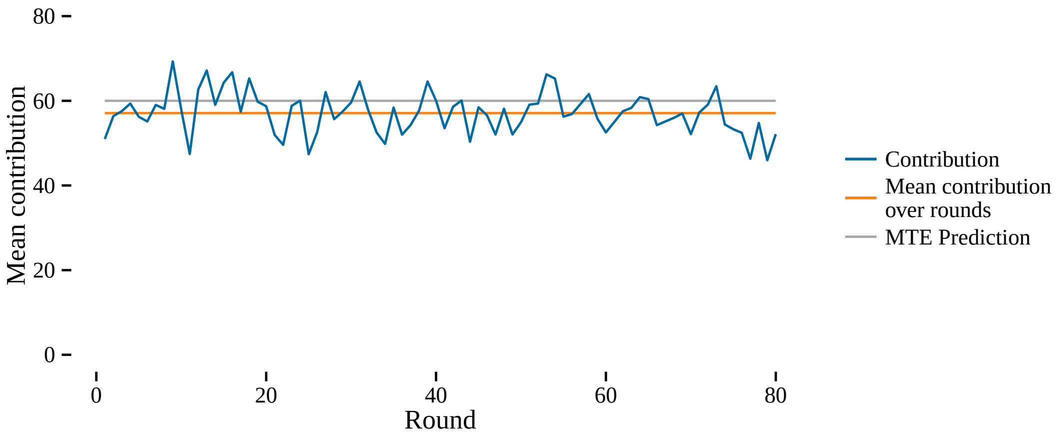

Figure 5.4: Mean contribution per round for the "lows" or subjects endowed with 80 tokens per round.

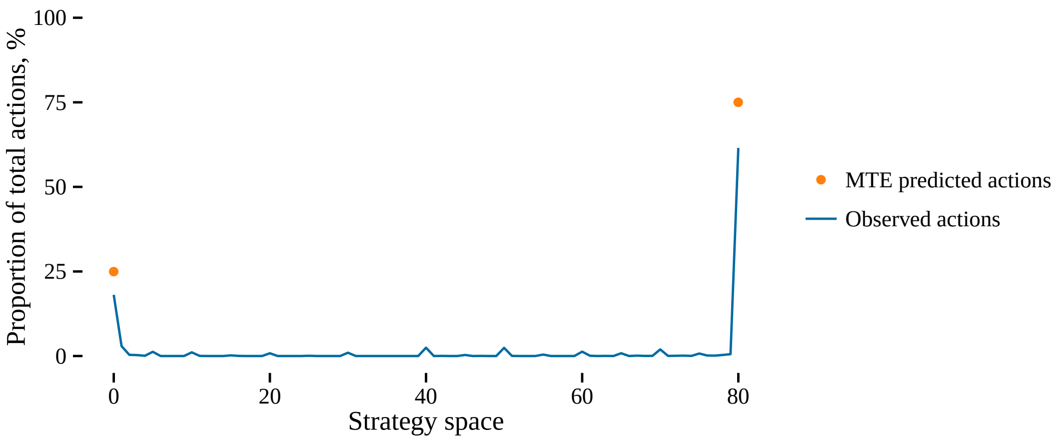

Figure 5.5: The choice proportions for the "lows" or subjects endowed with 80 tokens per round.

resulting in a mean contribution per round of $E(\bar{x}) = 60$ tokens[10] as depicted by the horizontal dashed line on figure 5.4. While there are variations throughout rounds, the subjects follow the predicted level resulting in a mean over all rounds of $\bar{x} = 57.1$ tokens, see figure 5.4.

Observation 5.3. The proportion of choices for the "lows" correspond closely to predicted NEE levels

The NEE prediction is for the subjects to choose only two out of 81 strategies. These two strategies are zero contribution and full 80 token contribution, in a fixed proportion of 25% of total choices being zero tokens and 75% of total choices being 80 tokens. These predictions are represented by circles in figure 5.5. The observed strategies correspond closely to these predicted levels with zero tokens being contributed in 18% of total choices and 80 tokens in 62% of total choices. Precision further increases throughout rounds reaching 21% and 64% respectively for rounds 21-80.

Jointly, observations 5.2 and 5.3 suggest that the NEE is a robust predictor for subject behavior within the GBM, even when the mechanism is made more complex and a different mechanism added on top of it.

5.3.3. Results for the higher endowed subjects

Looking at only the high endowed subjects, those with 120 tokens per round to allocate, the multi-tier equilibrium predicts that they will form a VCM social stratum bounded with a minimum contribution of 81 tokens. The highly endowed subjects are expected to contribute only the bare minimum of 81 tokens needed to maintain their elite cartel at the top of the GBM social stratum. With each of the "highs" contributing 81 tokens every round the mean contribution per round should be $E(\bar{x}) = 81$ tokens.

Observation 5.4. The "highs" stay within their class strategy space

Figure 5.7 shows that nearly all of the choices of the high endowed subjects are above 80 tokens. This indicates that the subjects must have realized their opportunity to guarantee themselves a position in the top tier by choosing strategies from within their class strategy space.

Observation 5.5. The "highs" systematically over-contribute

As shown by the solid line on figure 5.6 the mean contribution per round for the high endowed subjects turns out to be higher than the expected $E(\bar{x}) = 81$. The results from the experiments indicate a systematic over-contribution with a mean over all rounds of $\bar{x} = 96.39$ tokens. Given that the effective minimum contribution

[10] This expected mean contribution per round is found in the following manner $\frac{2\times 0+6\times 80}{2+6} = \frac{480}{8} = 60$.

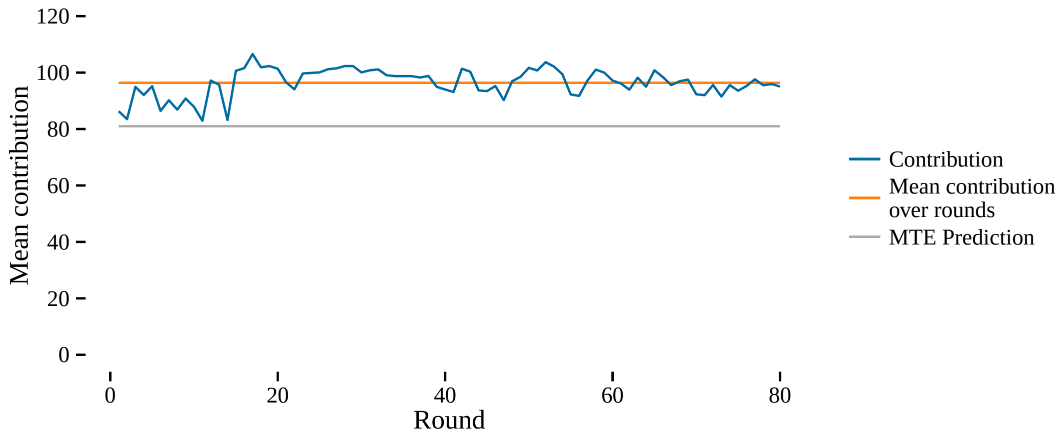

Figure 5.6: Mean contribution per round for the "highs" or subjects endowed with 120 tokens per round.

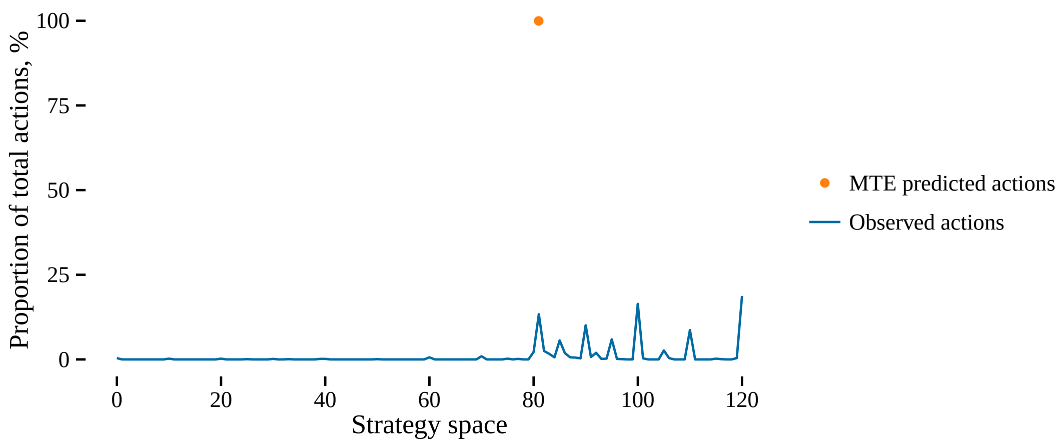

Figure 5.7: The choice proportions for the "highs" or subjects endowed with 120 tokens per round.

for the “highs” was 81 tokens, this translates into about 40% average contribution in VCM terms[11].

By looking at the choice proportions in figure 5.7 one can see the distribution of chosen strategies with the circle indicating the expected 100% of choices being a strategy of contributing 81 tokens. However, the “highs” select the predicted strategy in only 13% of all choices with the proportion increasing to 22% in the last 20 rounds. Higher contributions are considerably more common. It is also noticeable that the full contribution of 120 tokens is more common for all 80 rounds, being 19% of all choices, albeit the frequency decreases slightly in later rounds down to 17% for the last 20 rounds.

5.4. Conclusion

This section proposed an extension to the GBM model of Gunnthorsdottir et al. (2010a) with multiple endowment classes and a condition where type count is divisible by group size. By having the number of subjects within each endowment level fully divisible by group size one creates the possibility of what here has been called a *multi-tier equilibrium* where each endowment class forms its own social stratum and reaches a separate equilibrium. A general description of the *multi-tier equilibrium* was provided in Section 5.1.2.2. A version of the extended model was experimentally tested. There were two different endowment levels with a different division of subjects between the two endowment levels than previously investigated by Gunnthorsdottir et al. (2010b). Other parameters were however the same for comparability reasons.

The experimental results confirm that altering the number of subjects within each endowment class does have an impact on what sort of equilibrium emerges. While in Gunnthorsdottir et al. (2010b) subjects continue to play a NEE amongst themselves despite the altered endowment distribution, in the current experimental setting only the lower endowed subjects form an NEE. At the top of that mechanism the group of high endowed subjects face a social dilemma and lack proper incentives for cooperation. The mechanism they encounter is effectively a traditional VCM mechanism bounded by a minimum contribution necessary in order to segregate from the class below them.

Following are the two main conclusions of this chapter:

Conclusion 5.1. Lows play the NEE despite the more complex mechanism

The subjects endowed with 80 tokens per round do seem to play the NEE as predicted since they are effectively facing a GBM (Gunnthorsdottir et al., 2010a). The fact that there are other players who are more highly endowed does not affect the outcome or the subjects decisions since the higher endowed subjects in the top-tier are effectively isolated in their own “elite” group at the top of the hierarchy. The

[11] The contribution level was calculated as $\frac{96.39-81}{120-81}$.

existence of this elite group does not discourage the lower endowed from cooperating and contributing to the public good.

While keeping in mind the limits to external validity of the experimental method with regard to social policy, the conclusion nonetheless does suggest that the existence of an elite group does not necessarily reduce efficiency in the lower groups. This may be caused by the fact that while the higher returns in the top-tier are sustained by the contributions of the lower endowed subjects the higher endowed subjects do not take anything away from them. In other words, the lower endowed subjects suffer no cost from the higher endowed subjects and their abilities are not restrained by them. While such social organization may cause frustration and be of concern from some perspectives of justice (Rawls, 1999)[12], research shows that people believe that meritocracy and any resulting unequal outcomes are fair where abilities vary (e.g. Mitchell et al., 2003).

Conclusion 5.2. The highs show signs of unusually high cooperation levels

The subjects endowed with 120 tokens do understand the binding of a minimum of 81 token contribution and effectively form their own *elite* social stratum on top of the lower endowed subjects. However, they consistently over-contribute even though such behavior does not conform with traditional notions of rational actors. While some of the over-contribution could be attributed to errors, that alone might not be enough to explain both the magnitude and frequency. Subjects' cooperative tendencies are indicated by two observations; high overall contribution levels and less free-riding in the last round.

High overall contribution levels As the higher endowed subjects are facing a VCM type game, some over-contribution is to expected. Even though it is individually rational to contribute nothing, typical contribution levels in VCM games range from 40 - 60% of total endowments in round 1 (Ledyard, 1995). The contribution levels depend among other things on the chosen value of MPCR[13] (see e.g. Isaac and Walker, 1988b; Ledyard, 1995; Zelmer, 2003). Andreoni (1995) for example used a MPCR of 0.5, the same value as used here, and reports an average contribution level of 44% for a ten round VCM session. The traditional pattern for VCM games is for contributions to be higher in the first rounds and slowly decay towards zero throughout rounds (Ledyard, 1995). Because of this decline, average contribution level for all rounds may be lower when there are more rounds. While VCM experiments typically run for ten rounds, Gunnthorsdottir and Rapoport (2006) ran a VCM with US students for eighty rounds making the results better comparable to the current experiment. They find that the average contribution in the first ten

[12] Rawls (1999, see e.g. p. 91) voices concerns over pure meritocratic societies where equality of opportunity may cause inequality when the higher endowed supersede the less endowed. Since the abilities to utilize these opportunities are based on randomly distributed personal traits it is not pure merit that determines your fate.

[13] A higher MPCR increases the returns from the public account meaning that subjects have greater incentives to cooperate.

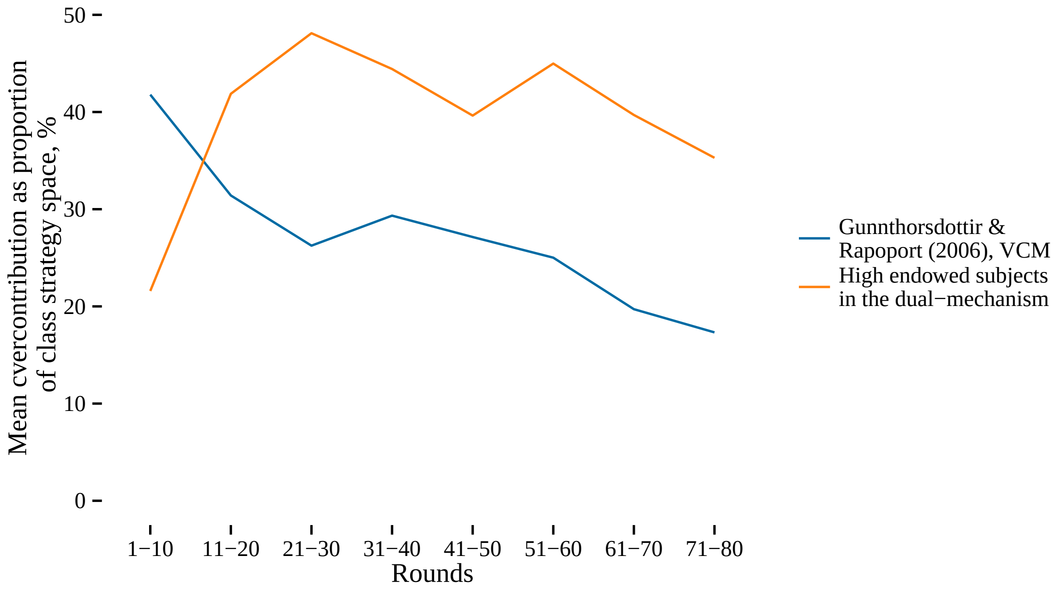

Figure 5.8: Comparison of ten round averages of mean over-contribution per round in the top-tier of the dual-mechanism and Gunnthorsdottir and Rapoport (2006).

rounds is 42% of total endowments but 27% for all eighty rounds. In observation 5, the average over-contribution[14] of the high endowed subjects is stated as 40% for all eighty rounds which is substantially higher than the levels reported by Gunnthorsdottir and Rapoport (2006) despite the same MPCR of 0.5. See figure 5.8 for comparison between the two studies.

Less free-riding in the last round The amount of free-riding in the last round of a VCM game is a measure of true cooperativeness. The last round should simulate a single round game where subjects do not need to worry about future interaction with the other subjects, such as reputation or retaliation. By comparing data from various experiments, Fehr and Schmidt (1999) report in a meta-analysis of twelve studies that about 73% of subjects free-ride in the last round of VCM games. Isaac and Walker (1988b) find that a higher MPCR reduces free riding in the last round with 83% of subjects free-riding in the last round when the MPCR is 0.3 but only 57% when the MPCR is 0.75. With an eighty round standard VCM and an MPCR of 0.5, Gunnthorsdottir and Rapoport (2006) find that 50% of the US student subjects contributed 0 in the last round. In the top-tier of the dual-mechanism free riding is very low in comparison. Only 19% of the "highs" (Icelandic student subjects) chose the free riding strategy of 81 tokens in the last round.

[14] Over-contribution is here measured as the level of contribution beyond the 81 tokens necessary to stay in the top-tier. A subject contributing 100 tokens would be over-contributing by $100-81=19$ tokens.

5.4.1. Thoughts on elevated contribution levels in the top class

As discussed above, the over-contribution observed in the top tier is substantially higher on average and more salient than in typical VCM experiments (see e.g. figure 5.8). Such over-contributions can both be attributed to errors and deliberate cooperative efforts (Andreoni, 1995). In post-experiment interviews, subjects in Ultimatum Games admit to also considering non-monetary motives (Henrich et al., 2001). The question is still open whether the elevated contribution levels are to be explained by larger errors or greater cooperation and in what proportion the reason is to be found in the dual-mechanism, cultural factors or simply pure coincidence.

Larger error In typical VCM games the free riding strategy is the minimum possible contribution. For the higher endowed subjects the free-riding strategy is an *interior strategy* with a contribution of 81 out of 120 tokens.[15] By contributing less than 81 the subjects risk being grouped with the lower endowed subjects and miss out on possible earnings. The higher endowed subjects effectively get *punished* if they err by contributing too little. This possibility might cause the subjects to keep a certain safety distance from the free-riding minimum. The dual mechanism might therefore be a cause of increased subject error.

Other sources of subject errors include not understanding the game or the instructions properly. Although subjects were explicitly asked to read the instructions they were not in the subject's native language[16] (see Appendix A for an overview of the experimental procedures and Appendix E for the instructions). Observation 3 in Section 4.3 discusses a slight learning trajectory for the Icelandic students in the baseline GBM which is not apparent for the US students. No cultural factors other than language are apparent that may cause increased errors but the existence of such factors must not be ruled out.

Deliberate over-contribution While a concrete explanation is still to be found regarding the reasons for over-contribution in VCM experiments some theories point to characteristic traits of the subjects. Gintis (2000) discusses so called *strong reciprocators* or subjects with a higher tendency to over-contribute and who are willing to take altruistic actions to try to reach a collaborative result, for example by cooperating even though other group members are not cooperating. Camerer and Fehr (2006) discuss how a higher proportion of strong reciprocators in the subject pool in a n-person prisoner's dilemma can increase the chance of a collaborating result

[15] This is reminiscent of Isaac and Walker (1998) who explored VCM games with interior Nash equilibrium strategies. Isaac and Walker found that over-contribution in VCM games cannot be explained by the fact that the Nash equilibrium is a corner strategy and that cooperative behavior is also prevalent when the free-riding strategy is interior.

[16] As the experiments were held at the University of Iceland one can assume that the native language of most subjects must have been Icelandic. The instructions however were in English.

emerging. While subjects acting as strong reciprocators focus on reaching a collaborative result, Fehr and Schmidt (1999) suggest equality may be a driving factor and that cooperative outcomes in public goods games may in some cases result from the inclusion of *inequity averse* subjects who are willing to sacrifice individual gain in order to increase equality. Fehr and Schmidt (1999) also discuss how collaborative results rest on the belief of subjects that others will cooperate and how even a small number of free-riders suffice to break the spirits of strong reciprocators and lead to a non-cooperative outcome. The level of cooperation may thus depend on the proportion of cooperators and free-riders.

Andreoni (1995) concludes that about 75% of subjects are in fact cooperative in their nature and research suggest that there may be a large group of people in different cultures who act as strong reciprocators (Fehr and Fischbacher, 2003) . Henrich et al. (2001) for example find considerable cultural variations when comparing contributions in Ultimatum Games in fifteen small societies. Cultural factors may perhaps explain the over-contribution in the top-tier but further research must be made before any conclusions are reached. A baseline VCM for Iceland would help isolate cultural effects from any possible consequences of the dual-mechanism.

5.4.2. Evidence for a discrete tit-for-tat strategy

With a non-binary set of choices, experiments show that the contrast is not so stark that all subjects either cooperate fully or not at all. Isaac et al. (1984) for example discuss three levels of cooperation; *strong free-riding* behavior where subjects contribute less than a third of their endowments, *weak free-riding* where subjects contribute more than a third but less than two-thirds and *Lindahl behavior* where subjects contribute more than two-thirds.[17] This is somewhat the pattern observed here. When looking at the individual choice paths for the high endowed subjects in the top-tier their choices are erratic and none of the subjects seem to follow a clear strategy of either cooperation or free-riding. In fact, a vast majority of subjects' choices were somewhere between the full contribution of 120 tokens and the minimum of 81 required to stay in the top-tier (see table 5.4).

Post experimental questionnaires revealed that the subjects chose these middle actions in order to somehow limit their exposure to being free-ridden off[18] while still wanting to maintain a level of trust, understanding that cooperation would lead to a more beneficial solution[19]. Some subjects found the best strategy for this to be to "follow the group" or to guess and then match the average contribution of the group, somewhat taking a neutral stand, neither wanting to free-ride nor to be free-ridden

[17] Isaac et al. (1984) actually define five levels of cooperation with the additional two polar extreme cases of *complete strong free-riding* and *complete Lindahl* where subjects, respectively, contribute nothing or fully.

[18] Rapoport and Eshed-Levy (1989) show that while greed is a more effective motivation for free-riding, fear of being free-ridden off also motivates such behavior.

[19] Similar explanations have been seen in post-experimental questionnaires from VCM experiments at the University of Arizona. Anna Gunnthorsdottir, verbal communication, March 17. 2015).

Table 5.4: The division of actions or contribution choices of the high endowed subjects in all four sessions.

	Count n	Proportion %
ACTION, x		
0...80	73	5.7
81	171	13.4
82...119	796	62.2
120	240	18.8
Total	1,280	100.0

off. In a way this can be seen as a *discrete tit-for-tat strategy.*[20] At the same time the strong reciprocators or those who were explicitly trying to raise group contribution did not necessarily make full contributions and those who realized the benefits of free-riding sometimes contributed more than the minimum in order to boost morale or to be less overt about it.

Perhaps a Kantian analysis could better describe the observed behavior, in other words one should separate subject's actions from their motives and rather categorize subjects based on their motives than their actions. By only looking at the actions we may not correctly categorize subjects who contribute something but not fully. Using this approach, a free rider is defined not by the action he takes but by the approach or intent towards the game.

5.4.3. Discussion

Jointly, the two conclusions above indicate that the NEE of the GBM is a robust phenomenon and is even observable when part of the subjects are exposed to a different mechanism. The conclusions also affirm what has previously been observed in public goods games; that subjects tend to cooperate more than traditional notions

[20] Evidence of subjects playing a tit-for-tat strategy in VCM games was already observed by Isaac et al. (1985). Fehr and Fischbacher (2003) discuss how strong reciprocators may attempt to guess and contribute the average contribution of other subjects and how the free-riding behavior of other subjects may eventually drive this average downwards, explaining the contribution decay apparent in VCM games. Axelrod and Hamilton (1981) show how the tit-for-tat strategy is highly successful in prisoner's dilemma tournaments and conclude that it is a utility maximizing and evolutionary stable strategy. Although cooperative strategies are not subgame-perfect in prisoner's dilemma games with finite horizons, John Nash theorized in a comment to Flood (1958) that given that enough rounds were played (i.e. 100 rounds) a game might be approximated to an infinite one. Kreps et al. (1982) showed that cooperative strategies may be rational for non-altruistic players in a repeated prisoner's dilemma if they have sufficient believe that their opponents are cooperative.

of rational actors predict.

However, the cooperation of the high endowed subjects goes beyond what would be expected in a traditional VCM. The question hence arises whether the difference can be attributed to cultural factors of Iceland, where the experiments were performed, or whether the over-contribution is a result of the dual mechanism model. As no VCM experiments have been conducted in Iceland there is no culturally independent comparison available. While Gunnthorsdottir and Thorsteinsson (2011) suggest that cultural factors in the GBM are minimal that finding does not rule out cultural differences in the VCM.

As a third explanation, the over-contribution may be caused by an unusually high proportion of strong-reciprocators (Gintis, 2000; Camerer and Fehr, 2006). Still, this high proportion of strong-reciprocators or the momentum generated by them would be highly unusual and continue to leave open the question of cultural factors. This paper thus calls for an Icelandic VCM experiment. For the same reason, a cross cultural comparison of the multi-tier equilibrium would be important in order to determine if the over contribution in the top tier is observable in other societies.

In case the increased contribution in the top tier turns out to be robust cross culturally, such a conclusion would call for further research on factors that could increase efficiency and cooperation in public goods mechanisms. However, if the over-contribution happens to be a special case of the Icelandic culture, it could be an interesting starting point in future cultural research.

6. General conclusions

This thesis consisted of two separate studies of models of public good production; a baseline cross-cultural replication study[1] of the *Group Based Meritocracy Mechanism* (GBM) by Gunnthorsdottir et al. (2010a) and a study where an extended combined mechanism was introduced where groups of subjects were endowed with different amounts of resources to contribute to the public good. For the combined mechanism, an overall Nash equilibrium solution called the *multi-tier equilibrium* (MTE) was proposed. In each study, observed data from experimental sessions was used to see if the predicted Nash equilibrium outcomes would accurately describe real-world behavior of subjects in each model.

The first study, discussed in Section 4, was a baseline replication study where subject endowments were homogeneous as first modeled by Gunnthorsdottir et al. (2010a). Replicating the homogeneous endowments condition served the purpose of testing the robustness of the results from Gunnthorsdottir et al. (2010a) under a different cultural setting. The results of Section 4 show that the GBM and the realization of the NEE is robust across the US and Iceland despite the two cultures being different on various dimensions. The results underpin the robustness of the NEE as a predictor for subject behavior in the GBM and show that subjects with different cultural backgrounds respond identically to the meritocratically based incentives of the GBM mechanism. The findings suggest that incorporating the meritocratic grouping aspect of the GBM mechanism is a potent method for increasing cooperation as measured by voluntary subject contributions in public goods settings. Finally, the results of Section 4 show that Icelandic students possess the same ability as US students to tacitly coordinate a complex asymmetric Nash equilibrium and that Icelandic students collectively favor a more efficient NEE equilibrium over a less efficient NBA equilibrium as prescribed by the payoff dominance criterion (Harsanyi and Selten, 1988).

The second study, discussed in Section 5, was an examination of how heterogeneous endowments of subjects would affect the outcome in a GBM. The heterogeneous endowment study was based on previous work by Gunnthorsdottir et al. (2010b) but introduced the possibility of full divisibility of subjects into groups of homogeneous subjects. In other words, subjects of different endowment levels could form uniform groups and avoid being grouped with subjects of different endowment levels. This condition radically alters the equilibrium structure of the game, making it considerably more complex. The *full divisibility condition* essentially turns the

[1] The cross-cultural replication study was published in the MODSIM2011 conference proceedings under the title "Tacit Coordination and Equilibrium Selection in a Merit-based Grouping Mechanism: A Cross-cultural Validation Study". See Gunnthorsdottir and Thorsteinsson (2011).

game into a multi-layered game of different mechanisms where subjects of each type form segregated, yet interconnected, mechanism *social strata*. A general equilibrium called the *multi-tier equilibrium* (MTE) was proposed. The MTE further describes the possible combination of mechanism social strata that can form and how they are combined into the final stack of social strata or the *combined mechanism*.

A two layer version of the combined mechanism was tested experimentally where eight out of twelve subjects were given 80 experimental tokens in endowment per round while the remaining four were given 120 tokens. Group size was set at four subjects per group. The MTE prediction was for the lower endowed subjects to form a GBM social stratum and coordinate an NEE while the higher endowed should form a VCM social stratum and contribute only a bounded minimum of 81 tokens per round. The experimental data showed that the lower endowed subjects accurately coordinated the NEE as predicted, despite the more complex mechanism. The data also showed that while the higher endowed subjects understood the binding minimum contribution of 81 tokens per round predicted by the MTE, the higher endowed subjects contributed amounts considerably higher than predicted or an average of 96.4 tokens. While over-contribution is typically observed in VCM experiments, the contribution levels observed here are considerably higher and more persistent throughout rounds. No conclusive explanation is available but the surprising level of cooperation observed by the higher endowed subjects compared to what is typically observed in a VCM can possibly be explained by either or both the combined mechanism or cultural factors of Iceland.

Further research

In spite of the cultural differences outlined in Section 4.1, subjects from the US and Iceland successfully coordinated the NEE. However, both countries are affluent Western societies with democratic governments and prevalent meritocratic social grouping. As a next step, the robustness of the NEE should be tested in developing countries or native communities and in communities where social organization is less meritocratic and more privilege-based. Additionally, as subjects in both locations were university students the study should be replicated using different demographic groups.

The results from the combined mechanism study leaves many questions to be answered. Since the over-contribution in the top-tier VCM type social stratum could result from either cultural factors of Iceland or the fact that this was a multi-level mechanism, the effects of each must be isolated. A VCM with Icelandic students drawn from the same subject pool would help reveal if there any cultural factors of Iceland who motivate subjects to cooperate on a greater scale than their US counterparts. Vice versa, a replication of the combined mechanism in a different culture may shed light on any effect that a multi-level mechanism may have on cooperation.

Depending on the chosen parameters, the GBM contains at least two Nash equilibria; the NEE and the NBA equilibria. While experimental results show that the NEE is preferred by subjects in a GBM on the aggregate level, the existence of certain alternative equilibria with positive contributions are not ruled out[2]; either additional pure strategy equilibria if the strategy space is discrete and restricted to a few options, or mixed and mixed-pure strategy equilibria. An effort to identify all possible Nash equilibria would help increase understanding of the GBM mechanism.

In both of the studies in this thesis, the actions of individual subjects oscillate unpredictably and subjects do not appear to follow a predetermined strategy. On aggregate however, the behavior seems to be systematic. A more profound analysis of post experimental questionnaires that were collected during the experiments for this thesis may help reveal the approach subjects take towards the game in order to better explain the observed behavior.

[2] As described in Section 2.2, Gunnthorsdottir et al. (2010a) already discovered alternative equilibria with very low contribution levels. They also found mixed strategy equilibria but demonstrated that their subjects did not play those.

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A. Detailed experimental procedures

This appendix describes in detail the experimental procedures used when conducting the experiments for this thesis. The first section explains the subject recruitment procedure. The next section describes the pre-experiment procedures and the final section lists the information that was given to the subjects.

A.1. Subject recruitment

Subjects signed up via a web form where they were asked for their name and email address as well as to choose the session for which they volunteered in case more than one was advertised at the same time. Prior to the sign-ups experimental sessions and timings were advertised by sending emails to a list serv containing email addresses for every student at the university except those who had specifically opted out of the list. According to a personal communication with an employee from the student registry at the University of Iceland the recruiting emails can be expected to have been sent to close to 9.000 email addresses (the size of the list).

After the subjects had registered for sessions using the web form, the first 18 signers received an email confirming their registration while extra signers, if any, were by email offered to change their registration to a session where there were free spots. As only 12 subjects were actually needed for each experimental session the overbooking rate was 50%. On average, about 14 of the 18 signed up persons showed up.

A.2. Pre-experiment procedures

In case more than the necessary twelve persons attended, twelve persons were chosen at random to stay for the experiment while the others were paid the show-up fee, thanked for signing up and showing up and encouraged to sign up for a later experiment. When all extra volunteers had been paid and left the room, the door was closed and locked so that no one could enter and disturb.

The twelve remaining subjects were greeted and randomly seated in front of computers running the pre-configured experimental software. The computers were all separated by blinders and furthermore an empty cubicle where possible. Each terminal was equipped with printed copies of the instructions, an information statement[1], a consent form, an empty receipt, and a post-experimental questionnaire.

Once seated, the subjects were asked to switch off cell phones and put all their belongings on the floor and told that no communication between subjects was allowed. Subjects were then asked to type their name into fields at the running computer software at their terminal, to sign the consent form and to read the instructions.

While the subjects read the instructions the experimenter walked by each terminal, collected the consent forms and paid the subject the show-up fee in cash.[2] The experiment started once all subjects had indicated that they had finished reading the instructions by pressing a pink button on the computer screen. At the conclusion of the experimental session, the subjects were called out one by one and privately paid their experimental earnings.

A.3. Information given to the subjects

Following traditional experimental economics protocols, and in particular copying the procedure by which the US comparison data had been collected, all subjects were given detailed instructions before the experiment started. Each subject had a printed copy of these instructions available at its cubicle and was asked to read it through before the experiment started. Additionally, the same instructions were projected by an overhead projector onto a screen that was in the front of the room, visible for every subject to guarantee common information, establish the fact that all subjects had the same information and convince subjects that there was no deception against any single subject. By looking at the projected instructions each subject was able to verify that she had the same and correct instructions.

Since the instructions were in English, subjects who had trouble understanding the instructions were assisted but the experimenter was careful only to elaborate on what was already included in the instructions and not give any hints on such topics as what decisions to make or what the research question was. At the end of the experiment, subjects were asked to leave the printed instructions at their terminal and not discuss the experiment with others.

While the full instructions can be found in Appendix E, the instructions included the following information:

- How much money the subjects had already been paid as a show-up fee and that future earnings would be based on performance in the experiment.

- A description of the decision task of allocating a fixed amount of experimental

[1] The information statement contained formal information on confidentiality, how the results would be used and whom to address with questions or complaints.

[2] Paying the subjects the show-up fee in cash before beginning the experiment was deliberate and was meant to emphasize that there really would be monetary payoffs to compete for and by that support the induced value of the experimental tokens. The same approach had been taken when collecting the US data.

tokens between two accounts and that subjects would be grouped depending on their allocation decisions.

- The allocation decision was referred to as *investment* and subjects were asked to choose between *investing* in two different *accounts*. The two accounts were named *group account* and *private account*. A single trial was referred to as a *round*.

- An explanation of the different nature of the two accounts, that the group account would be doubled before being divided equally between group members while the private account would neither return interest nor be shared with other subjects.

- The amount of experimental tokens each subject would receive and allocate each round (the endowment level) or alternatively the different endowment levels and how many subjects were in each category. In case of different endowment levels, the subjects would not be informed of which endowment level category they belonged to until at the first round of decision making.

- The number of rounds (80 rounds), participants (12 participants) and groups (3 groups)

- How earnings in experimental tokens were calculated each round and at what rate the total earnings would be converted into real life currency at the end of the experiment.

Care was taken to reduce any possible framing effects. Subjects were not asked to take on a particular role and were not explicitly given the context of a public goods game. Using the word *investment* to describe the allocation decision may have caused some framing effects although assumed to be minimal and non relevant.

B. MTE Equilibrium examples

This appendix hold a few examples of multi-tier Nash equilibriums obtained with different configurations of endowments and type-counts. These examples are generated using the action profile analyzer program in Appendix D.

Example 1: {GBM}{VCM}

Group size: 4

Multiplier: 2

		Strategy		Best Response	
Player	Endowment	x	E(r)	x	E(r)
0	80	0	160	0	160
1	80	0	160	0	160
2	80	80	133	80	133
3	80	80	133	80	133
4	80	80	133	80	133
5	80	80	133	80	133
6	80	80	133	80	133
7	80	80	133	80	133
8	120	81	201	81	201
9	120	81	201	81	201
10	120	81	201	81	201
11	120	81	201	81	201

Example 2: {GBM}{ForcedCooperative}{VCM}

Group size: 4

Multiplier: 2

		Strategy		Best Response	
Player	Endowment	x	E(r)	x	E(r)
0	80	0	160	0	160
1	80	0	160	0	160
2	80	80	133	80	133
3	80	80	133	80	133
4	80	80	133	80	133
5	80	80	133	80	133
6	80	80	133	80	133
7	80	80	133	80	133
8	81	81	162	81	162
9	81	81	162	81	162
10	81	81	162	81	162
11	81	81	162	81	162
12	100	82	182	82	182
13	100	82	182	82	182
14	100	82	182	82	182
15	100	82	182	82	182

Example 3: {GBM}{ForcedCooperative}{GBM}

Group size: 4

Multiplier: 2

		Strategy		Best Response	
Player	Endowment	x	E(r)	x	E(r)
0	80	0	160	0	160
1	80	0	160	0	160
2	80	80	133	80	133
3	80	80	133	80	133
4	80	80	133	80	133
5	80	80	133	80	133
6	80	80	133	80	133
7	80	80	133	80	133
8	81	81	162	81	162
9	81	81	162	81	162
10	81	81	162	81	162
11	81	81	162	81	162
12	100	82	200	82	200
13	100	82	200	82	200
14	100	100	194	100	194
15	100	100	194	100	194
16	100	100	194	100	194
17	100	100	194	100	194
18	100	100	194	100	194
19	100	100	194	100	194

Example 4: {GBM}{ForcedCooperative}{GBM}{VCM}

Group size: 4

Multiplier: 2

		Strategy		Best Response	
Player	Endowment	x	E(r)	x	E(r)
0	80	0	160	0	160
1	80	0	160	0	160
2	80	80	133	80	133
3	80	80	133	80	133
4	80	80	133	80	133
5	80	80	133	80	133
6	80	80	133	80	133
7	80	80	133	80	133
8	81	81	162	81	162
9	81	81	162	81	162
10	81	81	162	81	162
11	81	81	162	81	162
12	100	82	200	82	200
13	100	82	200	82	200
14	100	100	194	100	194
15	100	100	194	100	194
16	100	100	194	100	194
17	100	100	194	100	194
18	100	100	194	100	194
19	100	100	194	100	194
20	120	101	221	101	221
21	120	101	221	101	221
22	120	101	221	101	221
23	120	101	221	101	221

Example 5: {GBM}{ForcedCooperative}{VCM}{VCM}

Group size: 4

Multiplier: 2

		Strategy		Best Response	
Player	Endowment	x	E(r)	x	E(r)
0	80	0	160	0	160
1	80	0	160	0	160
2	80	80	133	80	133
3	80	80	133	80	133
4	80	80	133	80	133
5	80	80	133	80	133
6	80	80	133	80	133
7	80	80	133	80	133
8	81	81	162	81	162
9	81	81	162	81	162
10	81	81	162	81	162
11	81	81	162	81	162
12	100	82	182	82	182
13	100	82	182	82	182
14	100	82	182	82	182
15	100	82	182	82	182
16	120	82	202	82	202
17	120	82	202	82	202
18	120	82	202	82	202
19	120	82	202	82	202

C. Individual choice paths

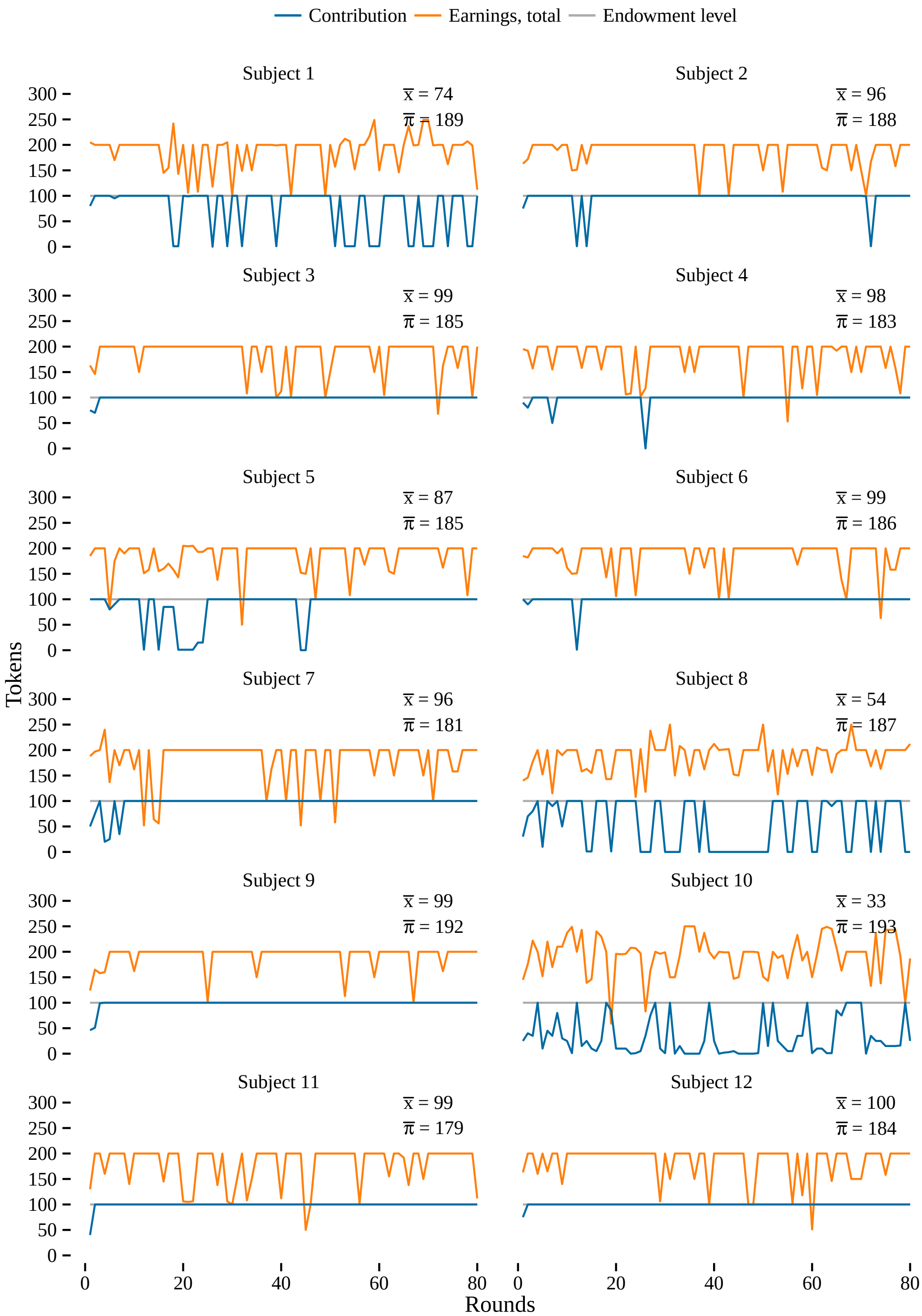
This appendix contains individual choice paths from the experimental data used throughout this thesis. In total there were eight experimental sessions held at the University of Iceland where data was collected specifically for this thesis. Additionally, data from four experimental sessions previously collected by Gunnthorsdottir et al. (2010a) was used. In total data from twelve experimental sessions was used in this thesis. The next three sections contain the individual choice paths for subjects in the following experiments respectively:

- 4x GBM sessions, George Mason University, 2005
- 4x GBM sessions, University of Iceland, 2011
- 4x MTE sessions, University of Iceland, 2011

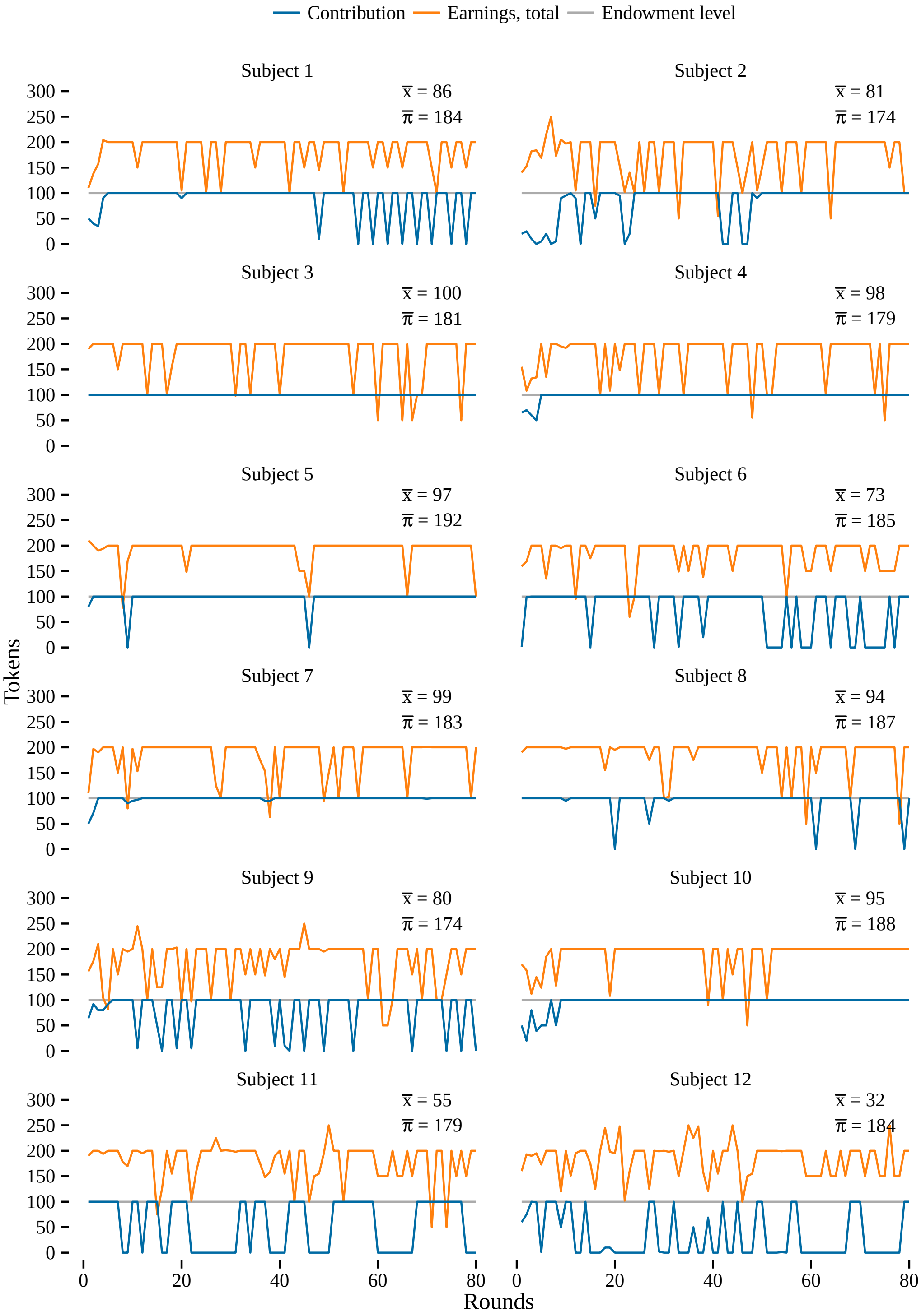
Individual choice paths describe the choices each subject made throughout rounds as well as the subject earnings. The token endowment of each player was charted as well for illustration purposes.

C.1. GBM at George Mason University in 2005

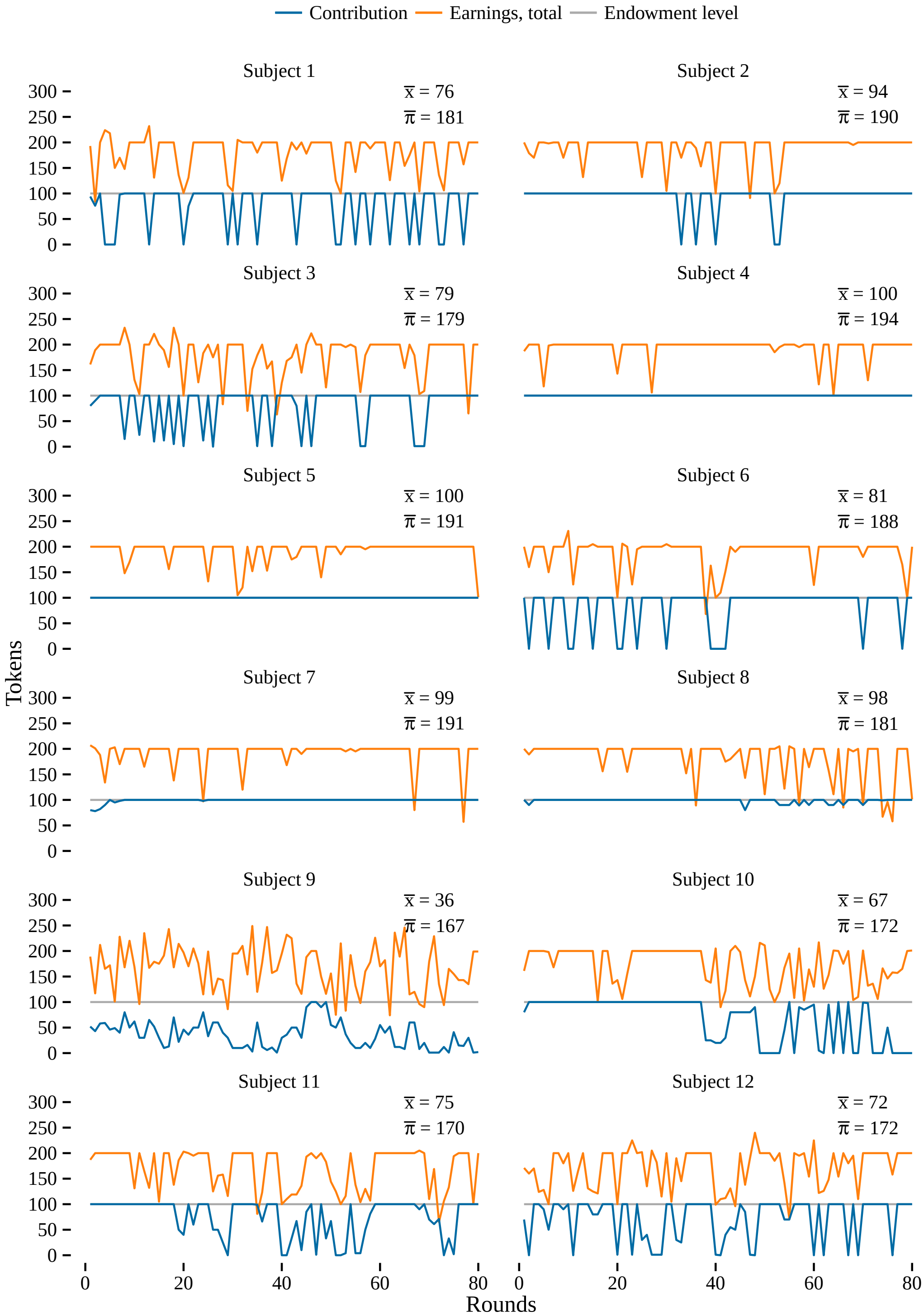
Session GVSM1: 2005-02-11 @ 12:00



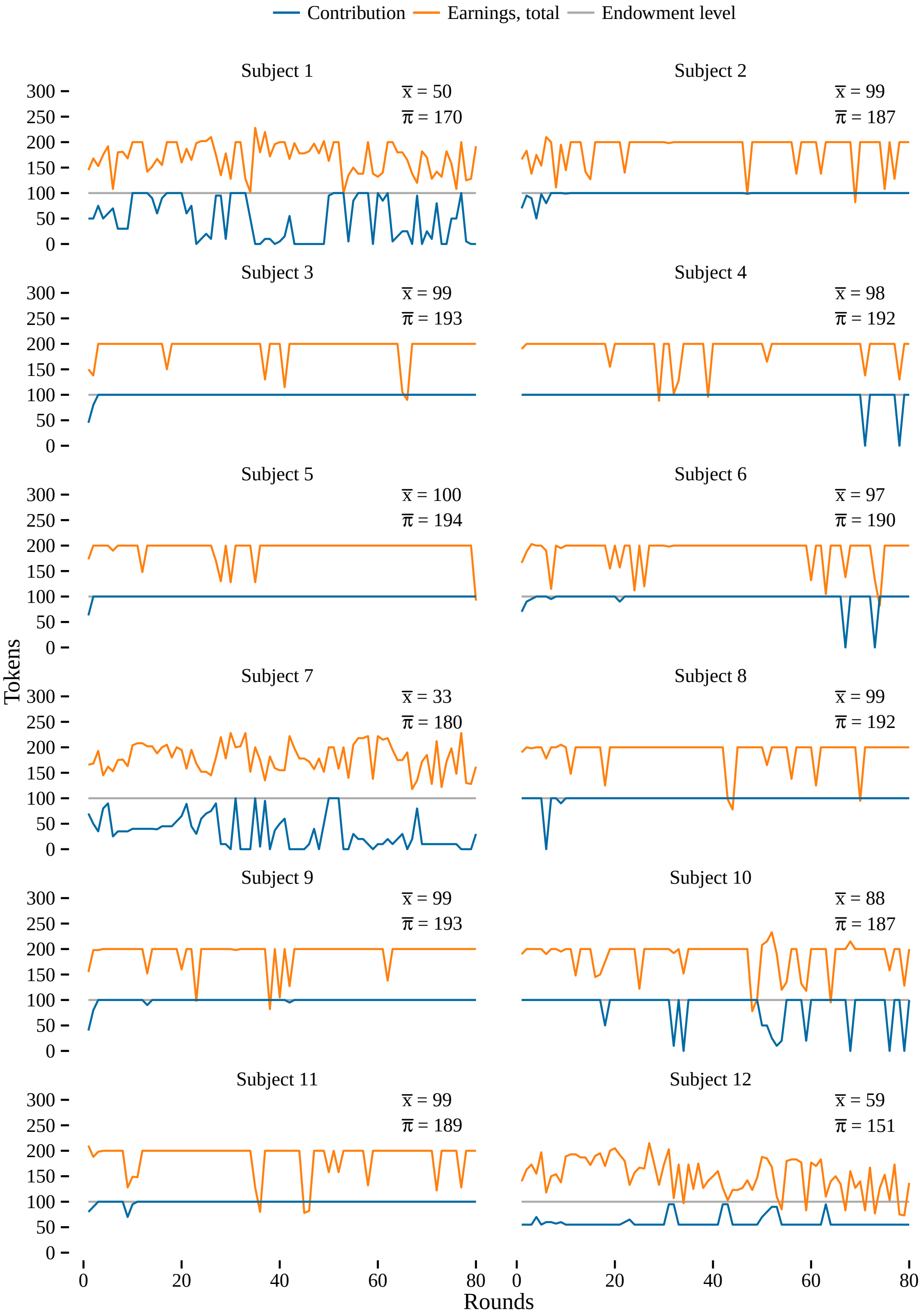
Session GVSM2: 2005-04-26 @ 14:00



Session GVSM3: 2005-04-27 @ 12:00

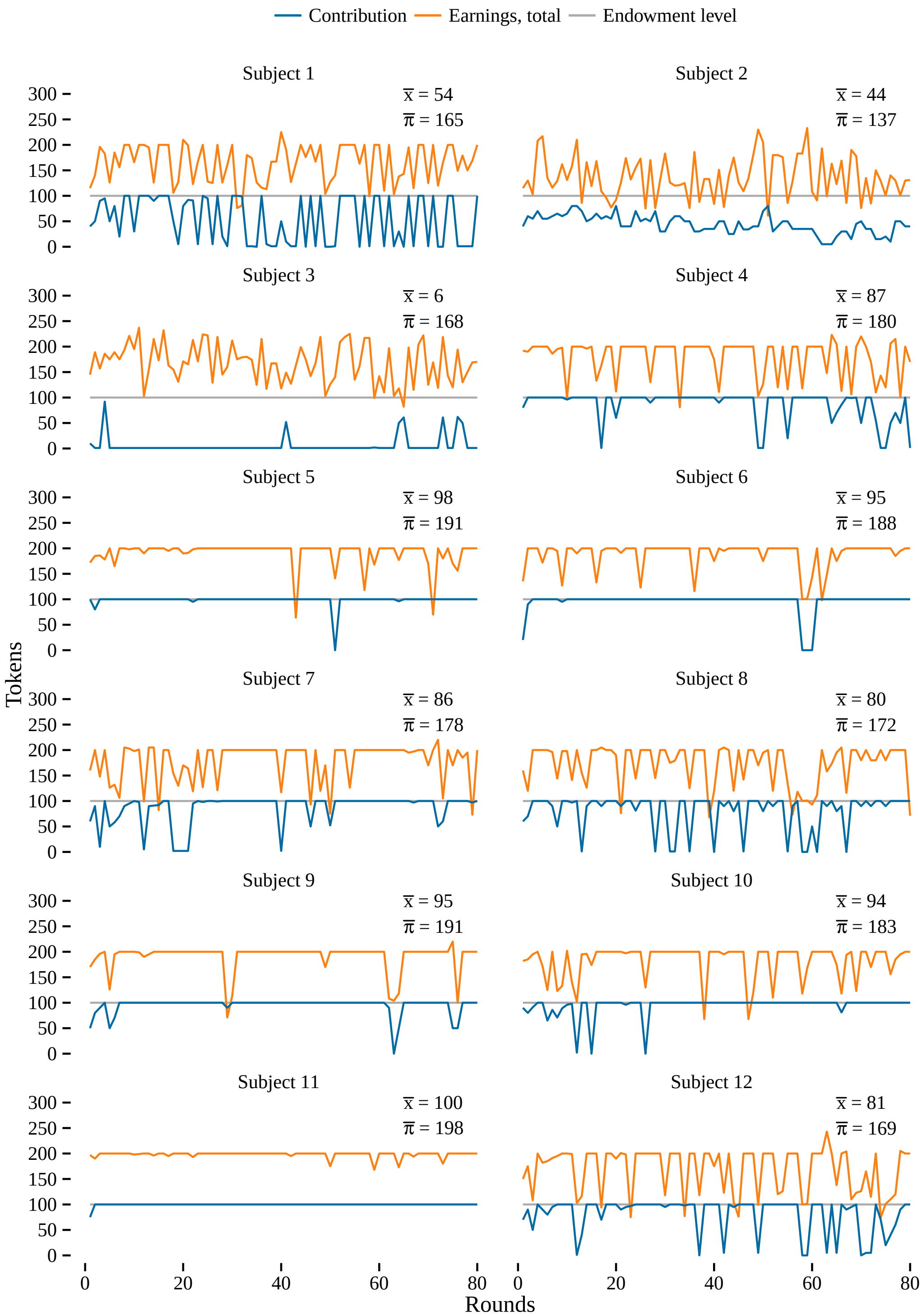


Session GVSM4: 2005-04-28 @ 12:00

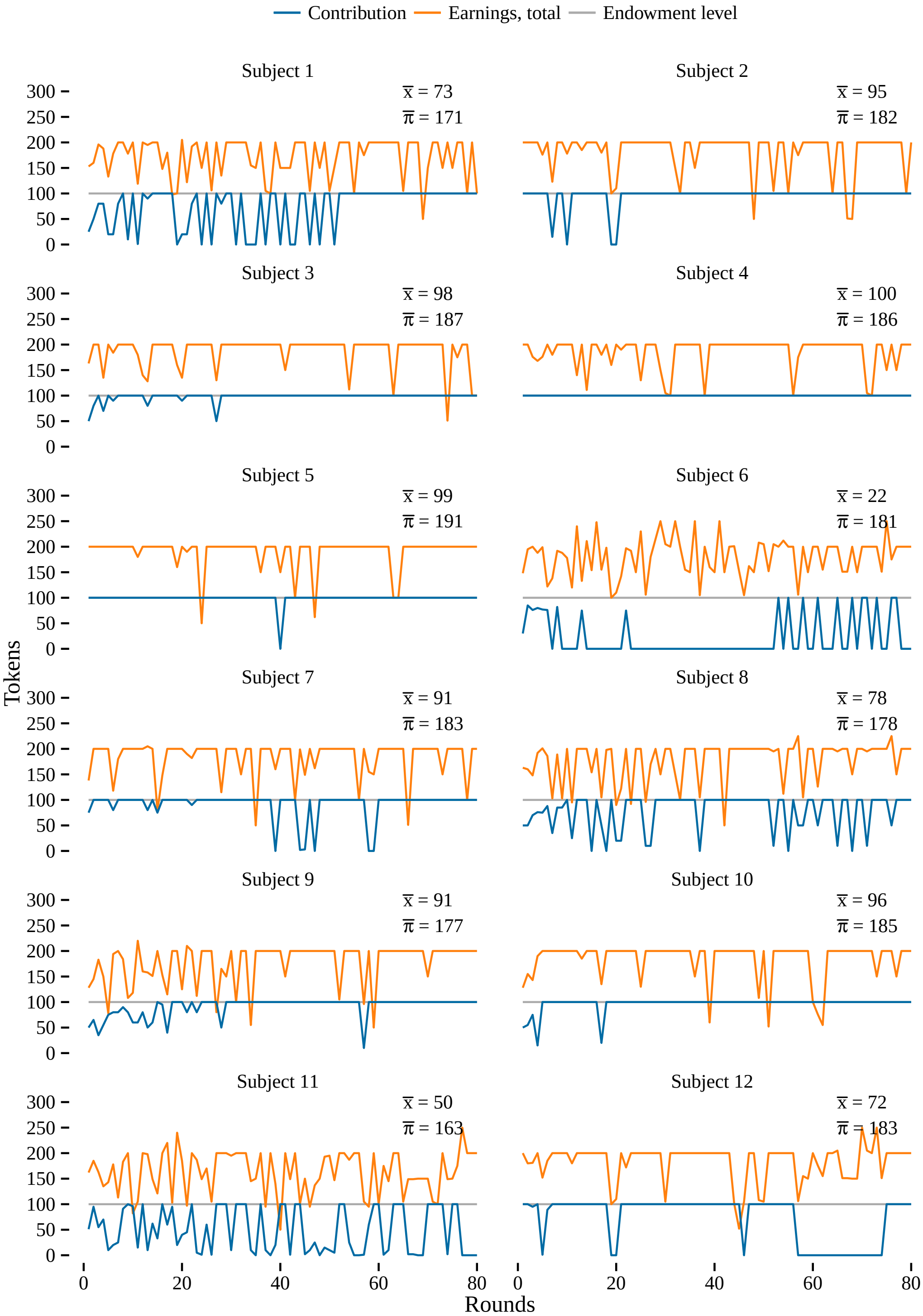


C.2. GBM at University of Iceland in 2011

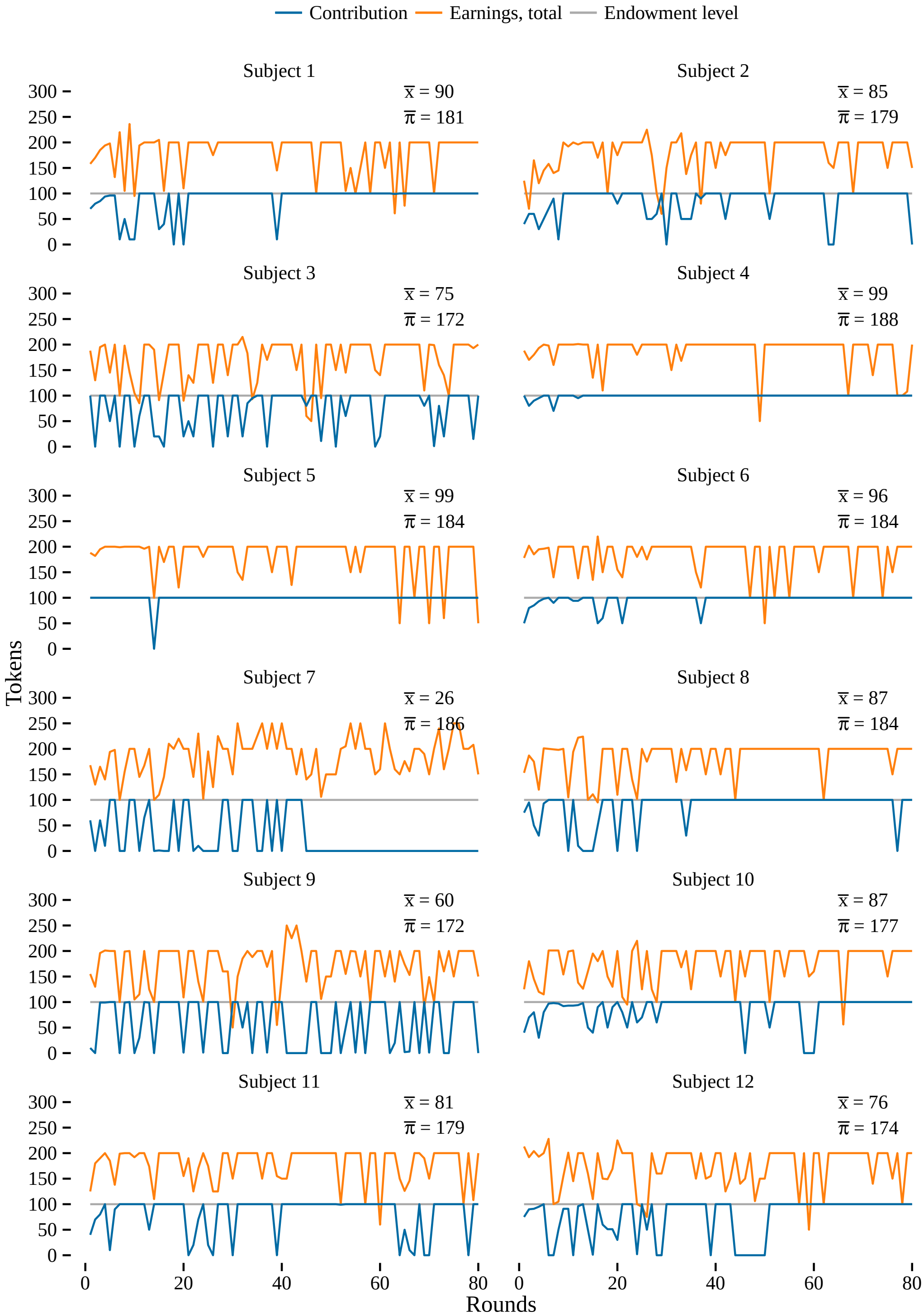
Session EE1: 2011-04-07 09:30



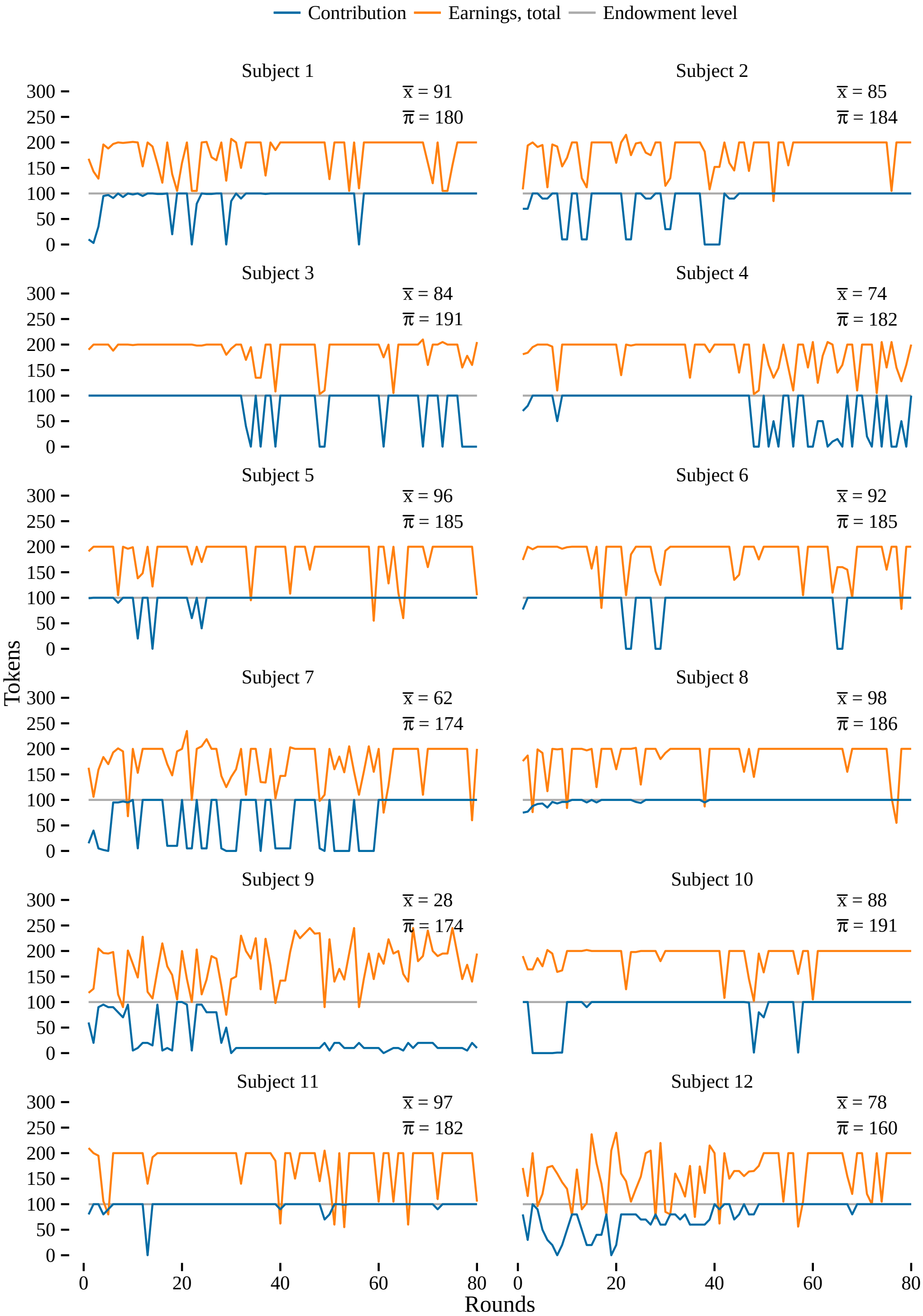
Session EE2: 2011-04-07 17:00



Session EE3: 2011-04-14 13:00

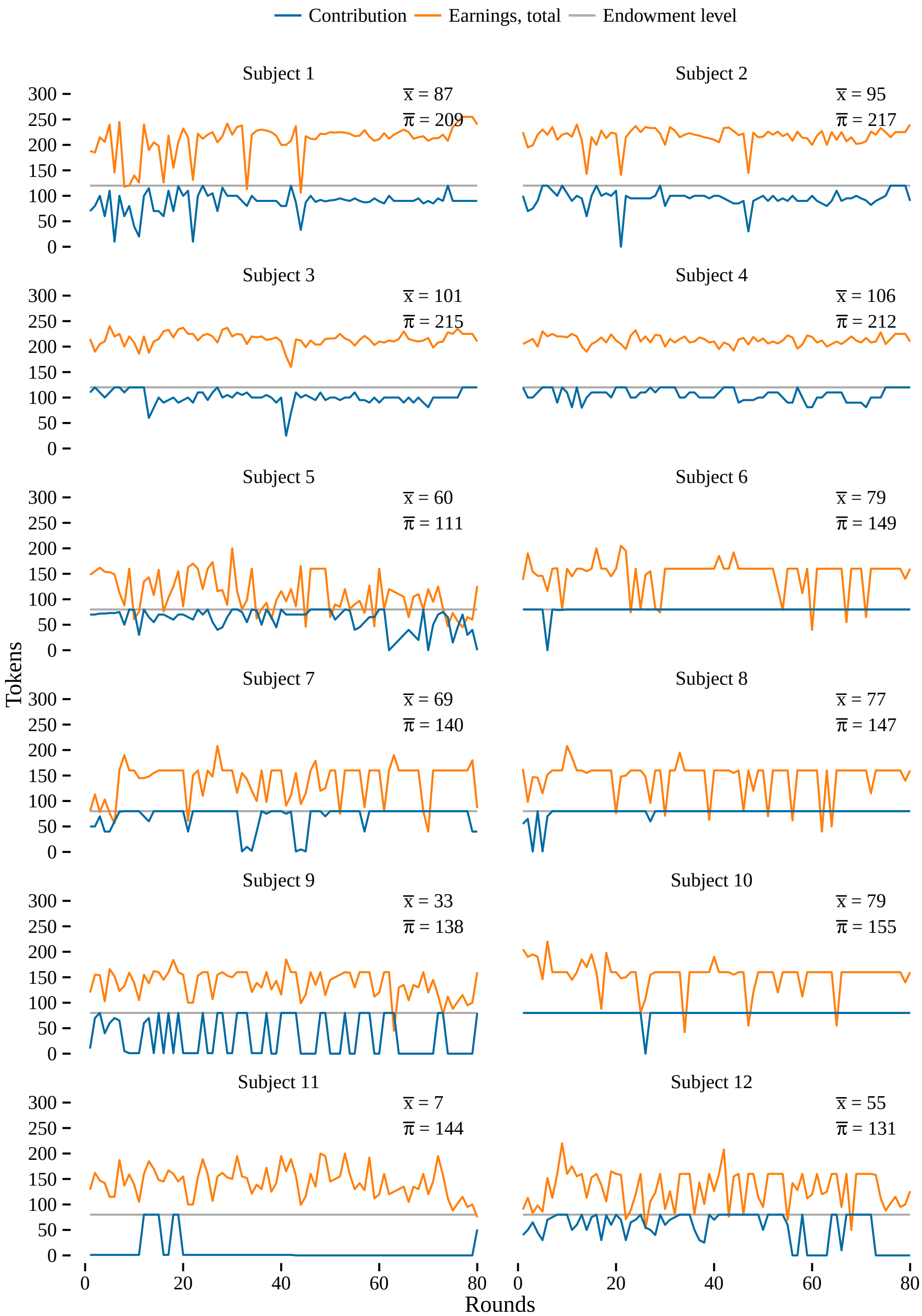


Session EE4: 2011-05-26 13:00

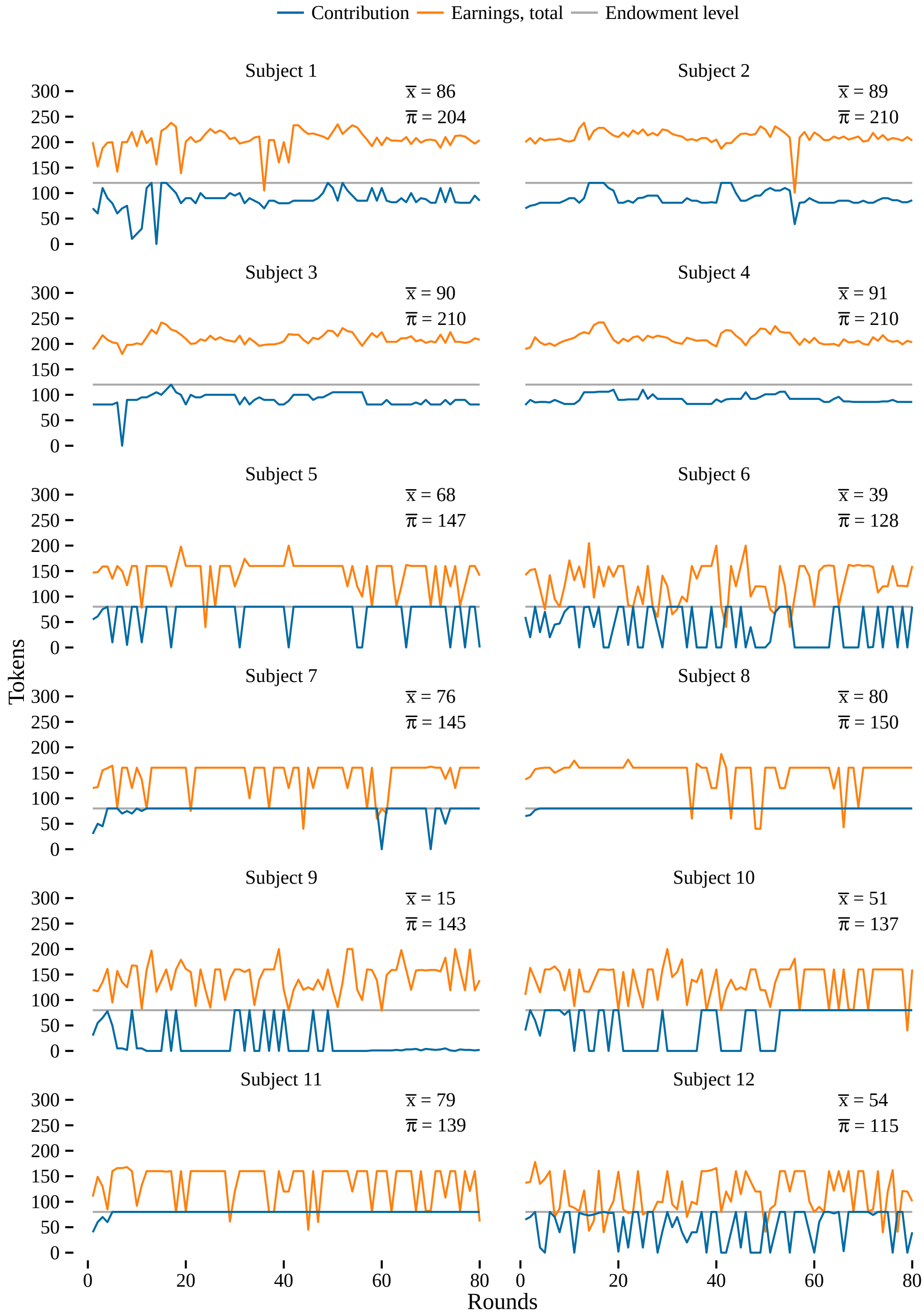


C.3. MTE at University of Iceland in 2011

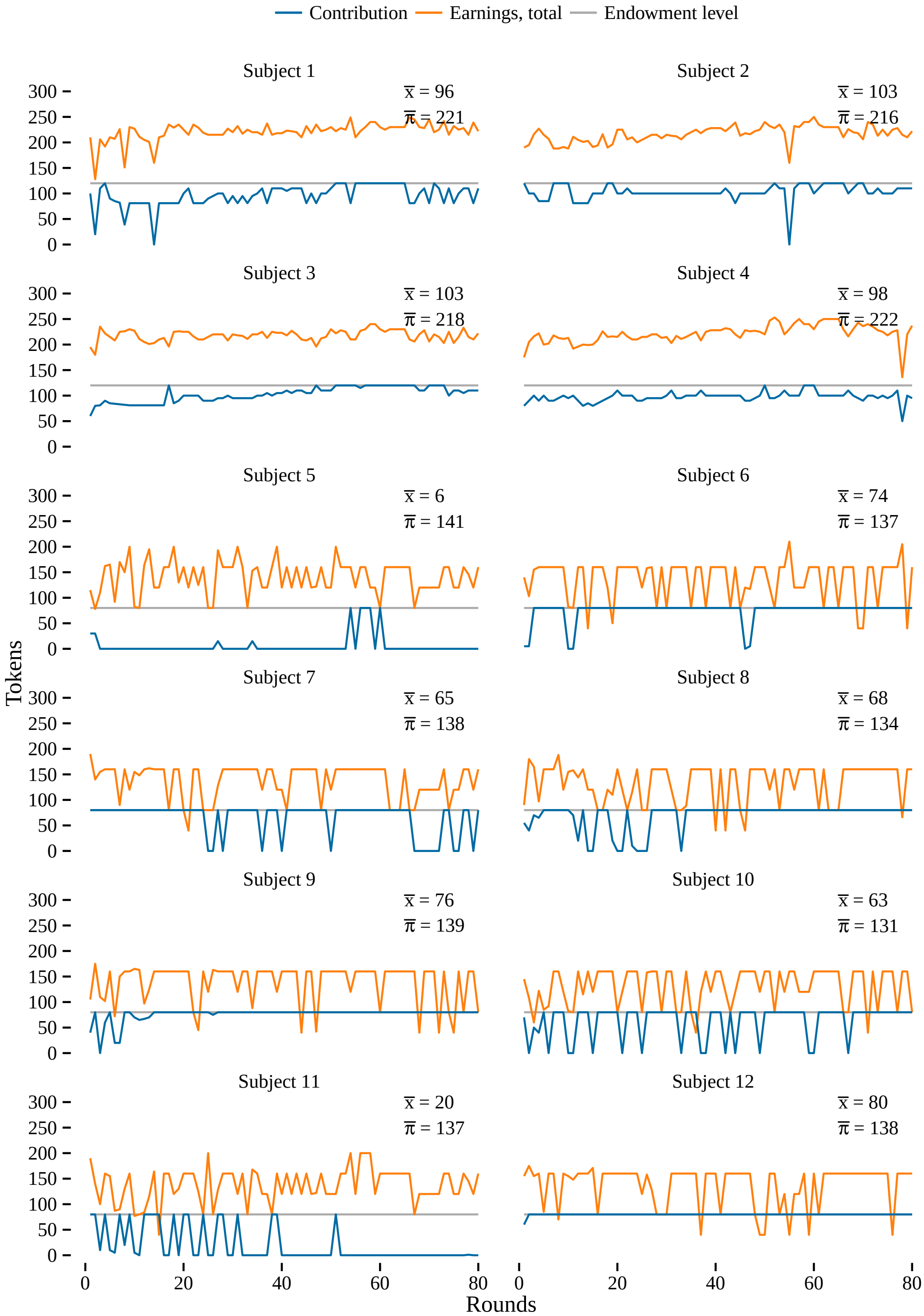
Session HE1: 2011-04-07 13:00



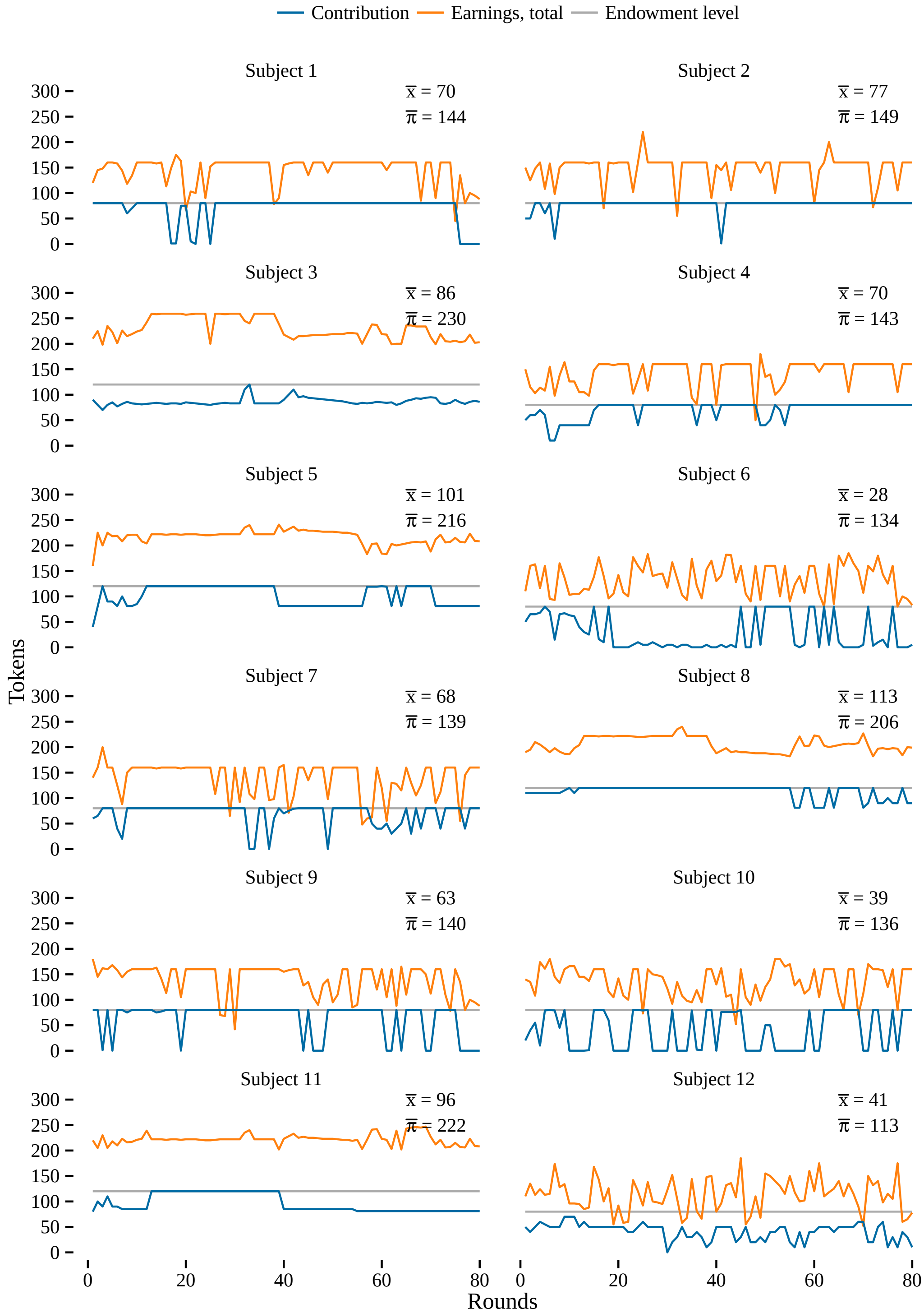
Session HE2: 2011-04-08 13:00



Session HE3: 2011-04-15 13:00



Session HE4: 2011-04-20 13:00



D. Source code for the action profile analyzer

A software program was written in order to check if certain action profiles were Nash equilibria. The program supports both GBM type games and extended mechanism type games. The program was written using the PHP programming language. Following are the main components of the program along with a usage example. Code relating to the user interface and display of results is excluded for brevity. The full source code is available on request as well as access to an on-line version of the full program.

Listing D.1: usage-example.php

```php
<?php
include 'Model/Player.php';
include 'Model/Game.php';
include 'Mechanisms/GBM.php';

// Set game parameters
$groupSize = 4;
$publicAccountMultiplier = 2;

// Create a mechanism object with the parameters
$mechanism = new Mechanisms\GBM();
$mechanism->setGroupSize($groupSize);
$mechanism->setPublicAccountMultiplier($publicAccountMultiplier);

// Define players and their endowments; 12 players, 100 tokens each
$endowmentsGVSM = array(100, 100, 100, 100, 100, 100, 100, 100, 100, 100,
    100, 100);

// Create a new game object
$game = new Model\Game($mechanism);
$game->addPlayerArray($endowmentsGVSM);

// Define an array with the action profile to be checked
// the array contains one action for each player 0..11
$actionProfile = array(
     0 => 0,
     1 => 0,
     2 => 100,
     3 => 100,
```

```php
     4 => 100,
     5 => 100,
     6 => 100,
     7 => 100,
     8 => 100,
     9 => 100,
    10 => 100,
    11 => 100,
);

// Get a list of player actions and their best responses
$responseMap = $game->getResponseMap($actionProfile);
var_dump($responseMap);

// ...or just check if this action profile is a Nash equilibrium
var_dump($game->isNashEq($actionProfile));
```

Listing D.2: Model/Player.php

```php
<?php
namespace Model;

class Player {
    protected $endowment;
    protected $mechanism;

    public function __construct($endowment, $mechanism) {
        $this->endowment = $endowment;
        $this->mechanism = $mechanism;
    }

    public function setEndowment($endowment)
    {
        $this->endowment = $endowment;
    }

    public function getEndowment()
    {
        return $this->endowment;
    }

    /**
     *
     * @param type $actionProfile   An array containing all other
     *                              players choices for a round
     */
    public function getBestResponse($actionProfile)
    {
        $bestActions = array();

        $actions = array();
```

```
        for ($action = 0; $action < $this->endowment+1; $action++) {
            $actions[$action] = $this->getExpectedReturn($action, $actionProfile);

            if (empty($bestActions)) {
                $bestActions[$action] = $actions[$action];
            } elseif ($actions[$action] > max($bestActions)) {
                $bestActions = array();
                $bestActions[$action] = $actions[$action];
            } elseif ($actions[$action] == max($bestActions)) {
                $bestActions[$action] = $actions[$action];
            }
        }

        return $bestActions;
    }


    public function getExpectedReturn($action, $actionProfile)
    {
        $actionProfile = array_merge($actionProfile, array("me" => $action));

        $publicAccountReturn = $this->mechanism->getPlayerExpectedReturn("me", $actionProfile);

        $privateAccountReturn = $this->endowment - $action;

        return $publicAccountReturn + $privateAccountReturn;
    }

    public function getResponseMap($actionProfile)
    {
        $bestResponse = $this->getBestResponse($actionProfile);

        $actions = array();
        for ($action = 0; $action < $this->endowment+1; $action++) {
            $actions[$action]['cells'][0] = $action;
            $actions[$action]['cells'][1] = $this->getExpectedReturn($action, $actionProfile);

            if (in_array($action, array_keys($bestResponse))) {
                $actions[$action]['class'] = "success";
                $actions[$action]['id'] = "bestResponse";
            }
        }

        return $actions;
    }
}
```

Listing D.3: Model/Game.php

```php
<?php
namespace Model;

class Game {
    protected $defaultPlayerType = "Model\Player";

    protected $mechanism;

    protected $players = array();

    protected $rounds;
    protected $currentRound;

    public function __construct($mechanism)
    {
        $this->mechanism = $mechanism;
    }

    public function getPlayerContributions()
    {
        foreach ($this->players as $player) {
            $player->getContribution();
        }
    }

    public function getMechanism()
    {
        return $this->mechanism;
    }

    public function getPlayerCount()
    {
        return count($this->players);
    }

    public function addPlayer($endowment, $type = null)
    {
        if ($type == null) {
            $type = $this->defaultPlayerType;
        }
        $this->players[] = new $type($endowment, $this->mechanism);
    }

    public function addPlayerArray($endowments, $type = null)
    {
        foreach ($endowments as $endowment) {
            $this->addPlayer($endowment, $type);
        }
    }

```

```
    public function getPlayers()
    {
        return $this->players;
    }

    public function setDefaultPlayerType($playerType)
    {
        $this->defaultPlayerType = $playerType;
    }

    public function getResponseMap($actionProfile)
    {
        $responseMap = array();

        foreach ($this->players as $playerId => $player) {
            $myAction = $actionProfile[$playerId];

            $actionProfileOthers = $actionProfile;

            // I only want to know what other will be doing
            unset($actionProfileOthers[$playerId]);

            $bestResponse = $player->getBestResponse($actionProfileOthers);

            $responseMap[$playerId]['bestResponses'] = $bestResponse;

            if (in_array($myAction, array_keys($bestResponse))) {
                $responseMap[$playerId]['isBestResponse'] = true;
                $responseMap[$playerId]['strategyReturn'] = $bestResponse[
                    $myAction];
            } else {
                $responseMap[$playerId]['isBestResponse'] = false;
                $responseMap[$playerId]['strategyReturn'] = $player->
                    getExpectedReturn($myAction, $actionProfileOthers);
            }
        }

        return $responseMap;
    }

    public function isNashEq($actionProfile)
    {
        $isNashEq = true;

        $results = array();

        foreach ($this->players as $playerId => $player) {
            $myAction = $actionProfile[$playerId];

            $actionProfileOthers = $actionProfile;
            unset($actionProfileOthers[$playerId]);

```

```
            $bestResponse = $player->getBestResponse($actionProfileOthers);

            if (in_array($myAction, array_keys($bestResponse))) {
                $results[$playerId] = true;
            } else {
                $results[$playerId] = $bestResponse;
                $isNashEq = false;
            }
        }

        if ($isNashEq) {
            return true;
        } else {
            return $results;
        }
    }
}
```

Listing D.4: Mechanisms/GBM.php

```
<?php
namespace Mechanisms;

class GBM {
    protected $groupSize = 4; // Default value
    protected $publicAccountMultiplier = 2; // Default value

    public function getGroupSize()
    {
        return $this->groupSize;
    }

    public function setGroupSize($groupSize)
    {
        $this->groupSize = $groupSize;
    }

    public function getPublicAccountMultiplier()
    {
        return $this->publicAccountMultiplier;
    }

    public function setPublicAccountMultiplier($publicAccountMultiplier)
    {
        $this->publicAccountMultiplier = $publicAccountMultiplier;
    }

    public function getMpcr()
    {
        return $this->publicAccountMultiplier / $this->groupSize;
    }
```

```

    public function getPlayerExpectedReturn($player, $actionProfile)
    {
        $myChoice = $actionProfile[$player];

        // sort player contributions into groups
        sort($actionProfile);
        $groupedContribs = array_chunk($actionProfile, $this->groupSize);

        // Count how many players choose each action
        $numActions = array_count_values($actionProfile);

        $chances = array();
        $groupReturns = array();

        // loop through all the groups
        foreach ($groupedContribs as $groupNum => $groupValues) {
            // count how many players in this group choose each action
            $counted = array_count_values($groupValues);

            if (isset($counted[$myChoice])) {
                // my action is in this group so there is a chance that I
                // will be in this group, the probability is:
                // "how many of those who select my action are in this
                // group divided by the total number of players that chose
                // this action
                $chances[$groupNum] = $counted[$myChoice] / $numActions[
                    $myChoice];
            } else {
                // there is no chance that I will be in this group
                $chances[$groupNum] = 0;
            }

            // find the return that one player in this group will get
            $groupReturns[$groupNum] = array_sum($groupValues) * $this->
                publicAccountMultiplier / $this->groupSize;
        }

        $eReturn = 0; // initialize variable

        // my total return is the expected return for a person in each group
        // multiplied by the probability that I will be in that group
        foreach ($groupReturns as $group => $groupReturn) {
            $eReturn += $groupReturn * $chances[$group];
        }

        return $eReturn;
    }
}
```

E. Instructions

This appendix includes the instructions used in the experiments held at the University of Iceland in 2011. There are two sets of instructions, one for the GBM condition and one for the combined mechanism condition. The instructions are labeled “s” (symmetric) and “as” (asymmetric) respectively but in order to not induce any framing effects the instructions were not labeled with the actual condition names.

s

INSTRUCTIONS

This is an experiment in decision-making. You have already earned 700 kr. for showing up at the appointed time. If you follow the instructions closely and make decisions carefully, you will make a substantial amount of money in addition to your show-up fee.

Number of periods

There will be 80 decision-making periods.

Endowments differ between participants

There are 12 participants in total. In each period, each individual receives an endowment 100 of experimental tokens.

The decision task

In each period, you need to decide how to divide your tokens between two accounts: a **private** account and a **group** account. The group account is joint among all members of the group that you are assigned to in that period. See below for the group assignment process and for how earnings from your accounts are calculated.

How earnings from your two different accounts are calculated in each period:

- Each token you put in the **private account** stays there for you to keep.
- All tokens that group members invest in the **group account** are added together to form the so-called "group investment". The group investment gets doubled before it is equally divided among all group members. Your group has four members (including yourself).

A numerical example of the earnings calculation in any given period:

Assume that in a given period, you decide to put 50 tokens into your private account and 50 tokens into the group account. The other three members of your group together contribute an additional 300 tokens to the group account. This makes the total group investment 350 tokens, which gets doubled to 700 tokens (350 * 2 = 700). The 700 tokens are then split equally among all four group members. Therefore, each group members earns 175 tokens from the group investment (700/4=175). In addition to the earnings from the group account, each group member earns 1 token for every token invested in his/her private account. Since you put 50 tokens into your private account, your total profit in this period is 175 + 50 = 225 tokens.

HOW EACH DECISION-MAKING PERIOD UNFOLDS AND HOW YOU ARE ASSIGNED TO A NEW GROUP IN EACH OF THE PERIODS

First, you make your investment decision

Decide on the number of tokens to place in the private and in the group account, respectively. To make a private account investment, use the mouse to move your cursor to the box labeled "Private Account". Click on the box and enter the number of tokens you wish to allocate to this account. Do likewise for the box labeled "Group Account" Entries in the two boxes must sum up to your endowment. To submit your investment click on the "Submit" button. Then wait until everyone else has submitted his/her investment decision.

Second, you are assigned to the group that you will be a member of in this period

Once every participant has submitted his or her investment decision, you will be assigned to a group with 4 members (including yourself).

The group assignment proceeds in the following manner:

All participants' contributions to the group account are ordered from the highest to the lowest contribution. Participants are then grouped based on this ranking:

- The four highest contributors are grouped together.
- Participants whose contributions rank from 5-8 form the second group.
- The four lowest contributors form the third group.

As said, you will be grouped based on your group account investment. If there are ties for group membership because contributions are equal, a random draw decides which of these equal-contributors are put together into one group and who goes into the next group below. For example, if 5 participants contributed 200 tokens, a random draw determines which of the four participants form a group of like-contributors and who is the one who goes into the next group below.

Recall that group membership is determined anew in each period based on your group contribution in that period. Group membership does not carry over between periods!

After the group assignment, your earnings for the round are computed

Earnings from a given round are computed *after* you have been assigned to your group. See the numerical example above for details of how earnings are computed after you have been assigned to a group.

End-of period message

At the end of each period you will receive a message with your total experimental earnings for the period (total earnings = the earnings from the group account and your private account added together). This information also appears in your Record Sheet at the bottom of the screen. The Record Sheet will also show the group account contributions of *all* participants in a given round in ascending order. Your contribution will be highlighted.

A new period begins after everyone has acknowledged his or her earnings message.

At the end of the experiment your total token earnings will be converted into kronur at a rate of 0.17 kronur per token.

as

INSTRUCTIONS

This is an experiment in decision-making. You have already earned 700 kr. for showing up at the appointed time. If you follow the instructions closely and make decisions carefully, you will make a substantial amount of money in addition to your show-up fee.

Number of periods

There will be 80 decision-making periods.

Endowments differ between participants

There are twelve participants in total. In each period, each individual receives an endowment of experimental tokens. **By a random process, eight participants receive an endowment of 80 tokens per round, and four receive 120 tokens per round. You receive the same endowment in each round of the experiment.**

The decision task

In each period, you need to decide how to divide your tokens between two accounts: a **private** account and a **group** account. The group account is joint among all members of the group that you are assigned to in that period. See below for the group assignment process and for how earnings from your accounts are calculated.

How earnings from your two different accounts are calculated in each period:

- Each token you put in the **private account** stays there for you to keep.
- All tokens that group members invest in the **group account** are added together to form the so-called "group investment". The group investment gets doubled before it is equally divided among all group members. Your group has four members (including yourself).

A numerical example of the earnings calculation in any given period:

Assume that your endowment per period is 80 tokens. In a given period, you decide to put 30 tokens into your private account and 50 tokens into the group account. The other three members of your group together contribute an additional 300 tokens to the group account. This makes the total group investment 350 tokens, which gets doubled to 700 tokens (350 * 2 = 700). The 700 tokens are then split equally among all four group members. Therefore, each group members earns 175 tokens from the group investment (700/4=175). In addition to the earnings from the group account, each group member earns 1 token for every token invested in his/her private account. Since you put 30 tokens into your private account, your total profit in this period is 175 + 30 = 205 tokens.

HOW EACH DECISION-MAKING PERIOD UNFOLDS AND HOW YOU ARE ASSIGNED TO A NEW GROUP IN EACH OF THE PERIODS

First, you make your investment decision

Decide on the number of tokens to place in the private and in the group account, respectively. To make a private account investment, use the mouse to move your cursor to the box labeled “Private Account”. Click on the box and enter the number of tokens you wish to allocate to this account. Do likewise for the box labeled “Group Account” Entries in the two boxes must sum up to your endowment. To submit your investment click on the “Submit” button. Then wait until everyone else has submitted his/her investment decision.

Second, you are assigned to the group that you will be a member of in this period

Once every participant has submitted his or her investment decision, you will be assigned to a group with 4 members (including yourself).

The group assignment proceeds in the following manner:

All participants' contributions to the group account are ordered from the highest to the lowest contribution. Participants are then grouped based on this ranking:

- The four highest contributors are grouped together.
- Participants whose contributions rank from 5-8 form the second group.
- The four lowest contributors form the third group.

As said, you will be grouped based on your group account investment. If there are ties for group membership because contributions are equal, a random draw decides which of these equal-contributors are put together into one group and who goes into the next group below. For example, if 5 participants contributed 200 tokens, a random draw determines which of the four participants form a group of like-contributors and who is the one who goes into the next group below.

Recall that group membership is determined anew in each period based on your group contribution in that period. Group membership does not carry over between periods!

After the group assignment, your earnings for the round are computed

Earnings from a given round are computed *after* you have been assigned to your group. See the numerical example above for details of how earnings are computed after you have been assigned to a group.

End-of period message

At the end of each period you will receive a message with your total experimental earnings for the period (total earnings = the earnings from the group account and your private account added together). This information also appears in your Record Sheet at the bottom of the screen. The Record Sheet will also show the group account contributions of *all* participants in a given round in ascending order. Your contribution will be highlighted.

A new period begins after everyone has acknowledged his or her earnings message.

At the end of the experiment your total token earnings will be converted into kronur at a rate of 0.17 kronur per token.