A Study on Heterogeneity in a Commons Dilemma: An Experimental Framework

Mihoko Tegawa

Department of Agricultural Economics
Macdonald Campus, McGill University
Montreal, Quebec

August 2010

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment for the requirements for the degree of Master of Science

Abstract

The commons dilemma is a situation where a group of individuals jointly use a resource, and an individual's rational decision to utilize the resource is sub-optimal from the perspective of the group. As a result, this can lead to overexploitation of the resource or underinvestment in its management. This dilemma can often be seen in common-pool resources (CPR). This situation is described by the CPR game, in which subjects decide how much they want to appropriate the CPR, which may return negative payoffs depending on how much they appropriate as a group. This thesis modifies the standard CPR game to represent the situation where two groups of users with different utility functions are spatially linked in the CPR. An example of this situation would be an upstream community that appropriates a river's water resource, which results in a change in the quantity or quality of the river, through pollution or extraction, to the downstream community that also utilizes the river. This thesis proposes a new experimental design to the standard CPR game that takes into account the heterogeneous utility functions of the two communities and the spatial dimension of the problem. Heterogeneity in interests may or may not increase efficiency in appropriating CPR. Behavioural implications are drawn from the re-designed CPR game.

Résumé

Un dilemme communes est une situation où un groupe d'individus utilisent une ressource et une décision rationnelle pour exploiter cette ressource de manière optimale dans la perspective de ce groupe. Comme résultat, cela peut mener à la surexploitation des ressources ou le sous-investissement dans ce management. Ce problème peut souvent être vu dans un common-pool resource (CPR). Cette situation est décrite par le jeu du CPR, qui a pour objet de décider combien ils veulent pour s'approprier le CPR, ce qui pourrait entrainer en retour un remboursement négatif dépendant de combien ils s'approprient/s'intègrent comme un groupe. Ce papier modifie les standards du jeu du CPR pour représenter la situation où deux groupes d'utilisateurs avec deux différentes fonctions utilitaires sont liés dans l'espace au CPR. Un exemple à cette situation serait l'impact qu'aurait une communauté en amont d'une rivière, à travers la pollution ou l'extraction, sur la communauté située en aval. Cette thèse propose une nouvelle étude expérimentale au jeu du CPR standard qui prend en compte les fonctions hétérogènes de ces deux communautés ainsi que la dimension spatiale de ce problème. L'hétérogénéité peut ou non augmenter l'efficience d'un CPR approprié. Des implications comportementales sont décrites par le nouveau jeu du CPR.

Acknowledgement

I am grateful to my supervisor, Professor Paul Thomassin for his advice and help for my work. I would like to thank Professor and Program Chair John Henning for his guidance and encouragement during my course of study at McGill University. I would also like to express my gratitude to Professor Jim Engle-Warnick of the Department of Economics, McGill University for his advice and suggestions, especially for the experimental design portion of the thesis.

My sincere thanks are extended to my family and all my friends for their encouragement, support, and advice. Any remaining errors are my own.

TABLE OF CONTENTS

1. Introduction 1
1.1. Overview 1
1.2. Problem statement 5
1.3. Aims and structure 6

2. Literature Review 8
2.1. Resource economics 8
2.2. The tragedy of the commons 13
2.3. Heterogeneity 23

3. Methodology 27
3.1. Theoretical model 27
3.2. Experimental design 35

4. Conclusion 57

References 62

Appendix: Instructions for the experiment 67

LIST OF FIGURES

Figure 1. Utility Function of Regular Appropriator 40
Figure 2. Theoretical Predictions 41
Figure 3. Utility Functions of Heterogeneous Appropriators 44
Figure 4. Utility Functions of Dependent Appropriators.....................................46
Figure 5. Theoretical Prediction 48
Figure 6. Ratio of the Two Appropriators over Total Wealth 49
Figure 7. Utility Function of Dependent Appropriator 52
Figure 8. Utility Function of Dependent Appropriator ($\sum x_j$* fixed) 53

LIST OF TABLES

Table 1. Three Experimental Designs 36
Table 2. Parameters for the Baseline Experiment 37
Table 3. Units Produced and Cash Return from Appropriation in the CPR 38
Table 4. Parameters for the Heterogeneous Experiment 42
Table 5. Units Produced and Cash Return from Appropriations in the CPR ($\sum x_i$* fixed) 45
Table 6. Dependent Appropriator's CPR Appropriation Matrix 47
Table 7. Dependent Appropriator's CPR Appropriation Function 52
Table 8. Units Appropriated and Cash Return from Appropriation in the CPR ($\sum x_j$* fixed) 53

1. Introduction

1.1. Overview

Sustainable management of natural resources has become an important subject in economics so as to avoid the tragedy of the commons as described by Hardin (1968). In other words, conservation needs to be considered when economic activities involve natural resources. In Ciriacy-Wantrup's book, *Resource conservation*, he classifies resources into two: non-renewable (or stock) resources and renewable (or flow) resources. Non-renewable resources require careful management; once the resources are appropriated, they are no longer available to others. Renewable resources also necessitate effective management; they can be destroyed like nonrenewable resources if appropriation of the resources exceeds the "critical zone" or a threshold (Ciriacy-Wantrup 1968). Mismanagement can easily lead to the destruction of a resource, which is often in the cases with open-access resources (Bromley 1997)[1]. Finding an effective institution to manage resources is a central question in conservation economics. It is an urgent issue that needs a response in order to alleviate degradation of resources where it is already happening, particularly when some appropriators degrade the resource but others do not. Conflict between resource users complicates the situation.

Contrary to some claims that common-pool resources (CPR) is a local and insignificant problem, CPR have increasingly drawn attention as a type of natural

[1] Open-access resources, res nullius, are the resources over which no property rights have been claimed. As Bromley (1992) pointed out, there was a confusion in common property and open-access resources. For details, refer to Bromley (1992, 1997).

resource problem (Dolsak and Ostrom 2003). It is true in a sense that it is a local issue because characteristics of CPR vary from place to place in terms of size, type of resource, and the institutions that govern them. It is also noteworthy that there are some common attributes that all CPRs share. According to Gardner, Ostrom, and Walker (1990), a CPR is a resource that is subtractable and is shared by multiple appropriators[2]. Subtractability implies that the resource that was harvested by one user is no longer available to another user. For example, when a tree in a forest is cut and transformed into a wood product, the same tree cannot be appropriated by another. In addition, when there is only one person who appropriates a resource, the resource is not considered as a CPR. The resource problems are different depending upon whether the resource is shared or not.

CPR itself does not always cause a dilemma, and in some cases self-governance among appropriators is achievable to avoid problems. Ostrom (2002b) defined the characteristics of a CPR as well as its appropriators that increase the likelihood of self-governance, which will be detailed later, whereas Gardner, Ostrom, and Walker (1990) defined conditions necessary for what is called the "CPR dilemma". According to the definition, in addition to being a CPR, the current situation of a CPR is suboptimal, and thus there exists at least one

---

[2] CPR does not specify the property regime. It can relate to open-access resources, common property resources, or other types of property. To differentiate them, the term limited-access CPR and open-access CPR were employed in Gardner, Ostrom, and Walker (1990). Baland and Platteau (1996) used an expression of "unregulated" and "regulated". An unregulated resource defines the access of the resource, and a regulated resource defines the rules of use of the resource in addition to the access. The standard CPR game refers to a limited-access CPR or unregulated property.
Dolsak and Ostrom (2003) mentioned another attribute of a CPR, which is costly to exclude outside appropriators from benefiting. But this is trivial in this study as the CPR game limits its attention to a limited-access CPR.

"constitutionally feasible[3]" set of strategies that could improve efficiency of the usage (Gardner, Ostrom, and Walker 1990, 336). Ostrom, Gardner, and Walker (1994) and Gardner, Ostrom, and Walker (1990) classified this CPR dilemma in terms of two management problems: appropriation and provision. An appropriation problem focuses on a flow of resources, the problems of which are the result of a negative externality that occurs when an individual's rational actions contradict with the interest of a group[4]. Generally a CPR game represents a dilemma in terms of this appropriation problem. A provision problem, on the other hand, limits its attentions to the stock side, the problems of which are the result of a lack of a positive externality when each individual fails to contribute to the maintenance of the CPR[5]. In reality, CPR face both management problems intertwined with one another.

The situations that CPR face can vary more than the standard CPR game[6] describes. Static resources such as pastures are suitable to the standard CPR game, because in many cases appropriators themselves are the only stakeholders. Non-static resources including water, however, involve various stakeholders with different perspectives as the resource changes location. More than one community

---

[3] "Constitutionally feasible alternative" is defined as a situation where (1) discounted benefits are greater than discounted costs (2) a consensus for an institutional change can be achieved (Gardner, Ostrom, and Walker 1990, 336).
[4] Appropriation problems are a matter of allocation in terms of (1) "rent dissipation" (quantity) (2) "assignment problems" (location and timing) (3) "technological externalities" (Gardner, Ostrom, and Walker 1990, 341).
[5] A public good game represents a provision dilemma (Ostrom, Gardner, and Walker 1994). Andreoni (1995) suggested asymmetric effects of a positive externality and a negative externality in that people are more cooperative in a public goods game for positive externality than in a common-pool resource game for a negative externality. A similar argument can be seen in other places including Prospect Theory. Nash's prediction in a CPR game predicts better than for a public good game. While subjects in CPR games tend to show their selfishness, in public goods games selfishness is not as evident as in CPR. Several publications explain this by altruism (Andreoni 1989, 1990, 1995; Croson 2007).
[6] The standard CPR game refers to the game in Walker, Gardner, and Ostrom (1990).

often shares the resource for different purposes. For example, an upstream community can appropriate a river's water resource, which results in pollution in the river or/and a reduction in water volume, whereas the downstream community may not use the resource directly but cares about its healthy state. The standard CPR game does not capture such a situation. The CPR game described in this thesis highlights a negative externality caused by one community, adding a victim player from the other community who bears the externality. In other words, the externality is uni-directional whereas it is reciprocal in a standard CPR game.

One might argue that privatization is as a remedy to solve the externality problem as shown by Coase (1960)[7]. Bromly (1997) emphasizes the importance of property regimes to address environmental problems and stresses the importance of a property regime change as a potential for solution, particularly for open access property[8]. In the case of a CPR, however, defining property rights is not always easy. As Ostrom (1990) pointed out, privatizing the CPR indicates dividing the property amongst a number of stakeholders. In order to divide the property, the resource needs to be not only static, e.g. pasture, but also be homogenous. Defining the rights to a non-static CPR, such as a fishery, is almost impossible. Therefore, privatization does not always solve the CPR dilemma[9]. Sarker, Ross, and Shrestha (2008) stated that the CPR approach, which

[7] Even though many CPR are privatized in some form, owned by individuals, groups, or governments, privatization here refers to individual ownership of the resource and individuals are free to sell and buy the rights of CPR. For work on privatization of CPR, see Dolsak and Ostrom (2003).
[8] Bromley (1997) classified four property regimes: state property, private property, common property, and open-access property. For the descriptions of each property regime, see Bromley (1997).
[9] This does not disqualify the importance of property regimes. But, a change in property regime may not always be feasible.

emphasized fostering cooperation, deserved more recognition as a means to help solve the CPR dilemma, especially with resources such as water. Following Sarker, Ross, and Shrestha (2008), this thesis examines an institution to foster cooperation with heterogeneous appropriators with special attention being paid to a non-static resource such as water.

1.2. Problem statement

A CPR can be degraded in terms of quantity and quality: the quantity of a CPR has been studied intensively while the quality has not received much attention (Sarker, Ross, and Shrestha 2008). This thesis highlights the quality of a CPR, which is not homogeneous and has time and spatial dimensions. This quality heterogeneity is caused by a negative externality that some users of the CPR impose on other users. Using the CPR game, the situation will be modeled where two different users, for example polluters and non-polluters, share the CPR that has time and spatial dimensions. It has a time dimension because the effects of appropriation occur consecutively not simultaneously. The CPRs the two users share are spatially linked because the effects of appropriation by one user affects the other. Although the standard CPR game assumes identical appropriators, this thesis incorporates the idea of pollution that makes a difference in terms of quality of the CPR, resulting in heterogeneity in the CPR.

Heterogeneity of stakeholders is a key to this study. This enables a CPR game to describe the situation where a CPR is shared by multiple groups with different interests, compared with the situation for a standard CPR game where a

CPR is shared by a group of homogenous appropriators. In other words, the modified version of the CPR game includes heterogeneous users with different utility functions instead of homogeneous users with the same utility function. When there exists another stakeholder who does not appropriate the resource, but cares about the resource, whether or not their existence induces cooperative actions among resource users will be considered in this thesis. Whether or not and how cooperation can be fostered under such a situation is the central question. Focus is placed on institutional development that would encourage cooperation, which here refers to collective actions of the appropriators, that take into account the interests of non-appropriators. Emphasis on the existence of non-appropriators may be enough to foster the cooperation. If so, these behaviours may be explained by altruism. If not, the incentives to induce cooperative action, such as rewards or sanctioning, may be required. The framework to examine these issues will be presented in this thesis.

1.3. Aims and structure

This study has been designed to present a framework to examine efficient institutions that have the potential to halt the degradation of natural resources with special attention being paid to CPR. The results of past CPR games have shown that CPR users fail to achieve optimal levels of appropriation, where marginal costs of appropriation equal marginal benefits (Ostrom, Walker, and Gardner 1992; Walker, Gardner, and Ostrom 1990, 1991). This research considers the consequences of the existence of non-appropriators who are only there to be affected by the behaviour of appropriators. As an example, upstream farmers or appropriators might increase their use of fertilizers for agricultural production and create pollution in a river. Downstream dwellers care about the river as an environmental good, but they do not appropriate it in the same manner as upstream farmers do. Considering the quantity of water, an example would be the use of water by producers for irrigation. If upstream farmers increase their use of irrigation water from the river, downstream dwellers will see a decrease in water level. This situation will be modeled by adding a new player, a non-appropriator into a standard CPR game, which creates heterogeneity of players in the game. Therefore, this study investigates whether the existence of non-appropriators can induce more cooperative action among appropriators to achieve a social optimum. To emphasize their existence, publicity and communication efforts from non-appropriators are introduced.

This thesis is structured as follows. The next chapter reviews the literature ranging from resource economics to psychology, which highlights what is unique about this study. In chapter 3, a theoretical model is explained in addition to introducing the baseline CPR model. The chapter also details an experimental design that matches the model. Finally, chapter 4 presents conclusions and recommendations.

2. *Literature Review*

2.1. Resource economics

Around the mid-20th century, resource economics and conservation economics emerged as one discipline in economics. Since then, many studies have framed environmental issues in an economic context and a comprehensive analysis has been carried out. Among them attempts to define the term "conservation" in economics have been made by some economists. Ciriacy-Wantrup (1952, 51) defined conservation "in terms of *changes* in the intertemporal distribution of physical rates of use." If the direction of the distribution is in the future, it's called conservation: if in the present, it means depletion. Conservation is an effort to put some emphasis on the use of the resource by future generations. Gordon (1954) described the problems pertaining to conservation or over-appropriation as an expression of generating no economic rents. This implies that over-appropriation does not necessarily lead to biological destruction of the resource. Scott (1955b, 30) emphasized a conservation policy for increasing "future usable supplies of a natural resource by present actions". Baland and Platteau (1996) distinguished conservation[10] from sustainability and argued that the former is more stringent in that it requires not only a level of well-being to be maintained but also a level of resource base or stock to be sustained above a carrying capacity[11]. As all these definitions imply, conservation does not automatically imply no appropriation at all. Instead, the efforts involve a search

[10] The authors use reproducibility as equivalent to conservation.
[11] If an exploitation of natural resources lies below a carrying capacity, it is a level of exploitation which does not threaten the regenerative ability of the resources.

for an equilibrium level of appropriation and an institution to stabilize appropriation at the equilibrium. This study does not seek an institution leading to non-appropriation of a CPR. Rather, what is needed is an institution to stabilize resource use at a sustainable[12], efficient level of appropriation, where the economic marginal costs of appropriating the resource are equal to the marginal benefits from harvesting them.

One of the important streams of the literature addressing resource economics is to treat the use of a natural resource as one special case of production (Cummings and Burt 1969; Gordon 1954; Gordon 1966; Gray 1914; Hotelling 1931; Jevons and Flux 1906; Scott 1955b, 1955a; Smith 1968). Jevons and Flux (1906) warned that the rate of economic growth at the time was not sustainable due to the fact that population grew while natural resources, such as coal, were limited. Gray (1914) has been recognized as a pioneer of the theory of exhaustible resources (Crabbé 1983; Gordon 1967). Gray (1914) demonstrated the interactions between a change in factor price and the rate of exhaustion, with special attention to the mining industry. This thesis examined the impact of, for example, an increase in the discount rate or the price of the resources on the rate of exhaustion. Later Hotelling (1931) completed Grey's analysis mathematically and it is known as the Gray-Hotelling pure theory of exhaustion. Gordon (1954)[13] made an early attempt to take a macrobiological approach to examine the use of common-pool natural resources. It is a dynamic model of interactions between the

[12] Strictly speaking, this CPR game does not have a time dimension included in it, which would be required to examine sustainability. Ignoring the intertemporal aspect, a static equilibrium is assumed to be the same as a dynamic one.
[13] Gordon (1954) defined the fishery as a common property resource, which is now usually regarded as an open access resource.

population of fish, quantity caught by man, and costs of fishing. The results implied that fishermen were likely to fish beyond the the rent dissipation level, and the equilibrium was in the state of overexploitation[14]. Scott (1955b) took a similar approach and bolstered the results of Gordon (1954). These studies suggest that the invisible hand does not work in natural resources, and economic theory implies over-appropriation of the resources. One important lesson from these studies is the necessity of sole ownership over a resource (Gordon 1954; Scott 1955b). In other words, the interests of individuals conflict with the interests of a group, and some mechanism is necessary to emphasize a group benefit.

Scott (1955a, vii) claimed that the appropriation of natural resources is "merely a special case of the using up of any productive asset"[15]. He emphasized the importance of a user cost in determining a conservation policy, and his suggested remedy focused on the role of government, for example to regulate. Using the model provided by Gray (1914) and Hotelling (1931), Gordon (1966) provided a proof of Scott (1955a) that the conservational argument to lower interest rates in order to give future demand more weight could actually encourage exhaustion of non-renewable resources. Smith (1968) modelled the relationship between exploitation of natural resources, behaviour of individual appropriators, and the overall impacts on the community or industry they belong to, with particular reference to common property. Smith (1968, 412) represented

[14] Another important implication from this study is that catch-per-unit-of-fishing-effort is not effective to prevent fishery depletion.
[15] Scott (1955a) regarded conservation as an equivalent to investment, but Ciriacy-Wantrup (1952) emphasized the difference between the two as conservation involves use rates of resources while investment refers to value changes of capital. The different definitions of conservation resulted in differences of these perspectives.

an externality of production in terms of recovery costs of resources or what he called "external diseconomies in production." The model allowed the size of the resources to enter into the cost function, but individuals do not have control over the size of the resource. Cummings and Burt (1969) modified Smith's model (1968) for non-renewable resources to match the conventional theory established by Gordon (1954).

Another approach to addressing this situation is through a property rights regime. Although the role of property rights in conservation policy was acknowledged earlier in Ciriacy-Wantrup (1952), not until the publication of Coase (1960) had property rights been regarded as a remedy to environmental problems. Coase (1960) stated that environmental problems, as described by Pigou, could be solved by internalizing the externalities through changing the property right regime instead of relying on tax policy. Bromley (1997) emphasized the importance of property regimes in addressing environmental problems, and he implied that a solution to the externality problem could be attributed to property regime change, specifically from open access property. Bromley (1997) argues that a common-property regime does not necessarily lead to degradation of the resource as economic theory suggests[16]. In fact, Ciriacy-Wantrup and Bishop (1975) demonstrated how common-property regimes could contribute to successful maintenance of resources. Berks (1992) introduced many cases in which co-management of the natural resources contributed to preventing a commons dilemma. Bromley (1997) attributed the failure of common property

[16] Bromley (1997) pointed out that there was confusion about common-property resources among researchers. The situations described by Hardin (1968) and Gordon (1954) actually refer to open access rather than common property.

to two reasons. First, internal governance such as compliance of rules by members stops working due to various reasons including an increase in population. The other reason is fragility of common property compared to private property, because external threats to common property do not receive the same attention from the state as private property unless the state has a particular interest in the resource. Common property resources are fragile, and are often managed under the common property regime because other property right regimes are not available or are too costly to implement. Baland and Platteau (1996) concluded that the efficiency of privatization could only be maximized under four conditions: zero enforcement costs, well-defined property rights, competitive markets, and perfect markets. When any of those conditins fail to hold, privatization may not achieve a best outcome.

The conventional theory of economics, which assumes that an individual is a self-interested utility maximizer, would conclude that maintenance of a CPR leads to over-exploitation of the resource. The conventional theory of natural resources, which was reviewed earlier, implies that a CPR is likely to result in the destruction of a resource and without an institutional change it is not sustainable. The economic modeling of resource use and its impact on the resource suggests that resource users appropriate the resource to rent dissipation. This is consistent with the situation Hardin (1968) described as the tragedy of the commons. The property right school also suggests that natural resources that are not privately owned, whether by an individual or by a state, may cause an externality problem. On the other hand, a careful examination of common-property resources demonstrated that the tragedy of the commons does not always accompany a CPR. In fact, a careful examination of case studies suggests that a common-property regime can be a successful institution to maintain the resource, if regulated properly (Berkes 1992; Ciriacy-Wantrup and Bishop 1975; Bromley and Feeny 1992). Poteete, Janssen, and Ostrom (2010) refuted the conventional theory of property rights from an empirical perspective, and identified a number of case studies that showed that without privatization some common-pool resources could be successfully managed and in other cases privatization had even led to the destruction of the resource.

2.2. The tragedy of the commons

The problems described by Hardin (1968) have attracted a lot of attention from many academics including economists. The tragedy of the commons refers to the situation where the interest of an individual conflicts with the group interest. For example, a fisherman maximizes his utility by catching as much fish as he can. If an increasing number of fishermen do the same thing with a fixed fish stock, the result is over-appropriation and possibly destruction of the resource. In the theory of public goods, such a situation is described by Olson (1965) as collective action. Olson (1965, 2) argued that:

> ···· unless the number of individuals in a group is quite small, or unless there is coercion or some other special device to make individuals act in their common interest*, rational, self-interested individuals will not act to achieve their common or group interests*. (emphasis in original)

In game theory, such a situation has been modeled as the prisoner's dilemma. The later work by Hardin found that the difference between the logic of collective action and the two-person prisoners' dilemma and examined the game theoretical framework to characterize the logic of collective action described by Olson (Hardin 1971, 1982).

Experimental economics brings a new perspective to the investigation of efficient, sustainable institution that could be used to govern a CPR. One of the early works in experimental economics is reported by Chamberlin (1948). Chamberlin (1948) examined neoclassical price theory using market experiments. Later, Smith (1962, 1964) completed Chamberlin's work. The other branch of the experimental economics literature is game experiments as represented by the prisoner's dilemma as well as individual-choice experiments to investigate choice under uncertainty including the Von Neumann-Morgenstern utility function (Davis and Holt 1992). This thesis employed experimental economics to shed light on another aspect of the CPR dilemma, which had not received attention in conventional economics.

One of the advantages in using an experiment is its control over an environment. It allows one to examine the impact of a change in one variable, holding other factors constant. Although the methods in econometrics can handle similar treatments, for instance on market data, the limitations on the methods as well as on data are recognized. The data obtained from experiments are real data from real people for the purpose of the analysis, and a cause-and-effect relationship is clearer than other data. Davis and Holt (1992) emphasized this advantage of experimental economics and a lack of data from natural markets makes it even more attractive to use laboratories to observe behaviour under a controlled environment. Fisher, Wheeler, and Zwick (1993, 105) stated that a major advantage is “the ability to test a general model in a simple case”. Replicability is also another advantage of laboratory methods (Davis and Holt 1992). Other researchers can reproduce the same experiment and examine the validity of the analysis independently. Plott (1991) elaborated on the advantages of experimental economics and explained why it had become important. According to Plott (1991), use of experiments has been expanding as the focus of economics shifts from specific economics to general theories. When the questions asked in economics involve examination of a specific policy such as monetary policy during the great depression, use of experiments seems unrelated. But, experimental economics can contribute to the evaluation of general models such as the law of demand.

On the other hand, there are some limitations to the use of the experimental approach in economics.[17] Experimentation is not very successful in observing intertemporal tradeoffs that are essential to macroeconomic analysis (Davis and Holt 1992). Fisher, Wheeler, and Zwick (1993) acknowledged that the relationship between a laboratory setting and the real world can be different. It is claimed, however, that if a theory does not work in a simple laboratory setting, it is less likely to work in a more complex real world (Davis and Holt 1992; Plott 1991).

As the use of experiments has expanded in economics, the same trend can be seen in resource economics (Fisher, Wheeler, and Zwick 1993). Fisher,

---

[17] For more details on the shortcomings and some means to solve them, refer to Fisher, Wheeler, and Zwick (1993) and Davis and Holt (1992).

Wheeler, and Zwick (1993) reported that in resource economics two areas have received a great deal of attentions: institutional design and valuation. To elicit a valuation, institutions and behaviour are controlled to reveal an underlying preference. On the contrary, to examine an institutional design, one observes a change in behaviour resulting from a change in institution. Evaluation of institutions has been advanced by the ability of an experiment to compare the efficiency of institutions (Plott 1991).

Before the CPR game was introduced by Walker, Gardner, and Ostrom (1990), a simulation of a commons dilemma was attempted by psychologists (Edney and Harper 1978; Dawes, McTavish, and Shaklee 1977; Messick and McClelland 1983; Jorgenson and Papciak 1981; Hamburger 1973; Kelley and Grzelak 1972). Kelly and Grzelak (1972) introduced a game described as an N-person prisoners' dilemma, where an individual chooses to act either for his own gain or for a common interest. Hamburger (1973) clarified the difference between the two-person prisoners' dilemma and the multi-person prisoners' dilemma. A multi-person prisoners' dilemma becomes a compound game when transformed from two persons, and some properties of a two-person prisoners' dilemma game do not hold for a multi-person prisoners' dilemma game (Hamburger 1973). Dawes, McTavish, and Shaklee (1977) ran an eight-person prisoners' dilemma game to examine the effects of communication in such a situation. Edney and Harper (1978) set up a common pool where individuals have access to a harvest, namely they can receive some gains from the pool without contributing to it. Their decisions involved whether they wanted to harvest the pool or sacrifice their opportunity of harvesting so as to increase the amount of the pool for the sake of the others. Jorgenson and Papciak (1981) followed the experiment run by Edney and Harper (1978) but focusing on an investigation of an institution to solve the dilemma by adding a communication opportunity, resource feedback, and identifiability of decisions. The resource feedback enabled the subjects to see how much resource was left in the pool while the identifiability of decisions made the names of the subjects and their decisions visible to others. Messick and McClelland (1983) also ran a similar experiment as Edney and Harper (1978) and analysed the problem by distinguishing social dilemmas (individual versus group rationality) and intertemporal dilemmas (short-run and long-run consequences) in a commons dilemma. The experiments in psychology are characterized as having a linear utility function and asymmetry between individual and group gains. Both of the decisions for an individual gain and a group gain reveal a linear form of returns. The asymmetry implies that while a gain for an individual is relatively large, the loss as a group is spread over the group.

A generally known CPR game refers to the experiment introduced by Walker, Gardner, and Ostrom (1990). It was designed to examine the dynamics of economic rents resulting from a behavioural choice. A brief description of the experiment is made here as the details will be presented later. Groups of eight subjects face decisions to appropriate a CPR or non-CPR resource. The return from a non-CPR is earned at a constant rate while the return from the CPR depends on a subject’s own decision and the decisions of the other members of the group. One of the big differences between this and the previous design is that

Walker, Gardner, and Ostrom (1990) employed a quadratic function for the gains from the CPR. This captures the situation where the appropriation of a CPR is more profitable at first but after it has reached the optimal an increase in CPR appropriation leads to a decrease in the return. This design is distinct from the earlier literature in that the CPR return rate varies, depending on the level of group appropriation, which implicitly focuses on the dynamics of economic rents rather than whether to cooperate-or-not alternatives. Although Kelley and Grzelak (1972) saw the psychological similarity between the prisoners' dilemma game and a commons dilemma, Baland and Platteau (1996) pointed out that the problems facing the prisoner's dilemma are not equivalent to those seen in unregulated common property, which involve co-ordination and leadership. The difference in these perspectives can be explained by Ostrom's (1990) arugument that those involved in the commons are not in the same situation as prisoners in the prisoners' dilemma because those in the commons can change the constraints put on them whereas the prisoners cannot. This shifts the focus of the problem from rationality of an individual versus a group to how to cooperate for self-governance.

As Plott (1991) stated, the supply of research on experimental economics creates demand for more study. The experimental design introduced by Walker, Gardner, and Ostrom (1990) was followed by various modifications of the game. Walker and Gardner (1992) modified the game to see the effects of probabilistic destruction of the resource. This is a repeated game and the subjects are faced not only with dissipation of economic rents but also with a probability of destruction of the CPR. Another institutional mechanism, although not common, that was added to the CPR game was the transfer of rewards. Van Soest and Vyrastekova (2006) studied the effectiveness of sanctions and the transfer of rewards based on distributional preferences of subjects. Although correlation between behaviours in the CPR game and distributional preferences was not clearly identified, the results from the CPR game found that transfer rewards were ineffective and they needed to be given continuously in order to be effective. The authors also suggested that the presence of the possibility to be sanctioned was sufficient to induce cooperative actions.

Communication, verbal discussion of gains between parties, has been a key element in the study of CPR. Ostrom, Gardner, and Walker (1994) examined the effect of communication in CPR situations. They ran experiments with three different types of communication: one-shot costless communication, repeated costless communication, and costly communication. The results suggested that one-time communication is so fragile that it did not increase efficiency. On the other hand, communication, if repeated, increased efficiency dramatically. Ostrom, Gardner, and Walker (1994) pointed out that the participants might have acted in order to keep a promise rather than to cooperate with the other participants. Even though the causality between communication and cooperation, that is whether or not communication fosters cooperation, is not clear, communication has been shown to be an effective means to induce some cooperative actions. Ostrom, Walker, and Gardner (1992) conducted experiments with sanctioning mechanisms in addition to communication opportunities.

Compared with the imposition of a sanction, communication was better in fostering cooperation. The first experiment allowed only communication. The next experiment had repeated opportunities for sanctioning only. Combining the two, they designed the third experiment with a one-shot communication followed by repeated opportunities for sanctions. The results suggested that the second experiment, with a repeated sanctioning mechanism, resulted in a worse situation than the baseline experiment in Walker, Gardner, and Ostrom (1990). Not only in economics have the effects of communication been studied intensively, but also in psychology. In psychology earlier attempts to study communication was with a multi-person Prisoners' Dilemma (Bixenstine, Levitt, and Wilson 1966; Caldwell 1976; Dawes, McTavish, and Shaklee 1977) and with a simulated commons dilemma (Brechner 1977; Edney and Harper 1978; Jerdee and Rosen 1974; Jorgenson and Papciak 1981). Their findings are consistent in that a positive effect of communication is an increase in efficiency. It is widely accepted that communication can encourage cooperation.

A series of experimental studies on the commons dilemma have confirmed the validity of economic theory, that when faced with such a dilemma individuals place more weight on their own interests than on a common gain and tend to overappropriate a CPR. Given the opportunity to communicate, however, individuals can be cooperative in seeking a group interest. Field studies have also provided different results from the theory. Many case studies have indicated that degradation of a CPR can be avoided and the resources can be successfully managed. Berks (1992) presented case studies in which successful management of the resources under the common-property regime was attained. In Japan, the concept of tenure was extended to the ocean and the fishermen had access to and ownership of ocean resources, which contributed to long-term conservation of the resources. In the case study from Mexico, development of a communal management system was observed by focusing on a recently created organization in the lobster fishery. In another lobster fishery from the North-Eastern United States, the fishermen were successful in sustainable management of the resources despite the fact that there were no legal communal rights over the resources. A case study of water from the Philippines demonstrated how community-based management could supplement a state property regime. Bromley and Feeny (1992) also introduced ample case studies from Asia and Europe. The Japanese case study illustrated how the commons survived despite a significant change in society. An interesting case study from Europe compared two similar commons in the Andes and in England. The one in the Andes survived, but on the other hand, in England it failed to prevent destruction of the resources. The authors attributed these different results to different social arrangements influenced by advancement in technology rather than technology itself.

From earlier experimental work, Edney and Harper (1978, 524) introduced some factors to avoid destruction of the resource. They concluded that the subjects were more likely to maintain the resources successfully when provided with the following: i) feedback about the level of the resource in the pool, ii) individual territories in the pool, iii) an extra large pool, and iv) communication within the group. Using many case study references, Ostrom (2002b) summarized the variables, which might encourage self-organization and the institutional design espousing a successful governance of the CPR[18]. The listed attributes of resources are: i) feasible improvement that resources are not deteriorated to the extent that it is no use to form an organization for improvement, ii) indicators of the condition of the resource available at a relatively low cost, iii) predictability of the resource flow, iv) spatial matter that the resource system is small enough to develop an accurate understanding of external boundaries and internal microenvironments (Ostrom 2002b, 5). The characteristics of appropriators are: i) salience, ii) common understanding, iii) low discount rate, iv) trust and reciprocity, v) autonomy, vi) prior organizational experience and local leadership (Ostrom 2002b, 5).

In addition, how these attributes are built into a bigger institutional design is equally important (Ostrom 2002b). Ostrom (1990) exploited many case studies with success, fragility, and failure, which were used to determine the principles that characterize a long-enduring CPR. The design principles characterizing a long-enduring CPR system are as follows: i) clearly defined boundaries, ii) proportionate costs to benefits and appropriation rules appropriate for the local conditions, iii) collective-choice arrangements where those affected by rules can participate in the process of modifying them, iv) monitoring, v) graduated sanctions, vi) conflict-resolution mechanisms, vii) a self-organizational institution is not challenged by external authorities (Ostrom 2002b, 10-11). The baseline CPR game meets the design principles i) and vii), and the other principles iii), iv),

[18] This part of the thesis heavily relies on Ostrom (2002), but a detailed discussion can be found in Ostrom (1990).

v), and vi) can be applied by modifying the game. The principle ii) can be adjusted by a utility function and the experimental setting. Allowing a communication opportunity involves iii) and possibly vi). According to these principles, neither the baseline game nor the modified game in this thesis can achieve a sustainable choice of appropriation for the CPR.

Although the role of these variables have gained some consensus among empirical researchers as being important, the effects of size and heterogeneity of a CPR on governance are unresolved, which Ostrom (2002b) called "theoretical puzzles" (Ostrom 2002b, 12). Size and heterogeneity are highly correlated. As the size of a group becomes bigger, heterogeneity within the population is more likely. Many authors have reported that the smaller the size is, the more likely homogeneity of appropriators will be attained, thus leading to a successful governance of the resources. However, Ostrom (2002b) pointed out that it is more important to examine how size or heterogeneity affects the benefit-cost calculation, especially the cost of producing and distributing information, rather than to focus on size or heterogeneity by themselves.

2.3. Heterogeneity

While many publications have reported that communication in a CPR dilemma has a positive effect as introduced above, heterogeneity has been argued as being a serious deterrent to cooperation, especially when there is a significant difference between appropriators (Hackett 1992; Hardin 1982; Johnson and Libecap 1982). Both the game theoretical study by Hackett (1992) and the empirical study by Johnson and Libecap (1982) emphasized the role of heterogeneity in a commons dilemma. Ostrom (2002b) reminded us that heterogeneity could take many dimensions, which makes it difficult to gain consensus about its effects on performance. As stated earlier, the effects of heterogeneity, particularly on the calculation of costs associated with information dissemination, should be of concern rather than the direct relationship between heterogeneity and performance. For example, heterogeneity in endowment wealth, interests, culture or social identity can have an impact on the estimation of the benefits and costs associated with appropriation or self-governance.

As the limitations of a baseline CPR game that assumes homogeneous appropriators were acknowledged (Dolsak and Ostrom 2003; Ostrom 2002b), variations of the CPR game to represent heterogeneity were attempted. Heterogeneity can take on multiple dimensions, for example understanding of CPR, culture, or endowment wealth. Using empirical data from India, Naidu (2005) identified three important dimensions that heterogeneity has on collective action: wealth, social identity, and interests. She argued that contrary to the conventional belief, a high level of wealth heterogeneity did not necessarily discourage cooperation among resource users. Experiments with wealth heterogeneity reached a similar conclusion. Hackett, Schlager, and Walker (1994) examined the effects of heterogeneity on an individuals' ability to coordinate. They represented heterogeneity by varying the initial wealth. Even with heterogeneity in endowment wealth, communication has been shown to be an efficient means to induce cooperation and thus increase efficiency in a CPR game

(Ostrom, Walker, and Gardner 1992). In other words, wealth heterogeneity did not destroy the effects of communication completely and instead encouraged collective action. In fact, the literature identifies heterogeneity as a major hindrance for cooperation (Ostrom 2002a) and yet the results suggest that even in a situation with heterogeneous appropriators, communication played a robust role in increasing efficiency. Hackett, Schlager, and Walker (1994), however, pointed out that it might depend on homogeneities in other attributes of appropriators. Heterogeneity in endowment wealth may not be considered as a significant heterogeneity affecting the benefit-cost calculus of a CPR.

Another approach to heterogeneity was attempted by Schnier (2009). Schnier (2009) assumed heterogeneity of the resources and introduced spatial linkage between two CPRs. By employing different parameters for the same utility function, this spatial linkage was modeled as both uni-directional and bi-directional. For the uni-directional game, investment in one CPR reduces the return in the other CPR but not the other way around, whereas the bi-directional game allows reductions in returns both ways. The decisions of appropriators involve the assignment of their endowment between the two spatially linked CPRs. Unlike heterogeneity in appropriators, this heterogeneity in resources does not impose much threat to cooperation among appropriators, but rather implies a change in strategy resulting from interactions between the two spatially connected CPRs. The result of the uni-directional game, which is somewhat similar to the situation this thesis describes, suggests that investments in the CPR, the return of which depends on the other CPR, were proportionally lower.

Kagel and Wolfe (2001) conducted a three-person ultimatum game, adding a third victim player to the standard game. The proposer splits money between the three, and the second player accepts or rejects the proposal. If accepted, the money will be distributed as proposed, but if refused, the third player gets everything. This third player is there to be affected by the decisions of the two other players. This situation involves fairness and concerns income distribution between the players. Similar modifications can be found in Chan et al. (1999) with a public good game and in Falk, Fehr, and Fischbacher (2005) with a prisoners' dilemma game. The thesis will assume heterogeneity in interests resulting from a having different calculation structure of appropriation costs. Heterogeneity in appropriators' interests results in having different cost structures of appropriation, and especially when the appropriation of the resource in one community imposes a negative externality on the other community.

3. *Methodology*

3.1. Theoretical model

This thesis's approach to heterogeneity is similar to Kagel and Wolfe (2001). The CPR experiment proposed in this thesis contains subjects with different utility functions, which allows the game to embody the heterogeneity of the appropriators in a distinct way from past experiments. In other words, one group, being a so-called victim in Kagel and Wolfe's (2001) experiment, is dependent on the behaviour of the others for their own utilities. The experiment will examine whether or not the existence of this dependent population influences independent appropriators' behaviours. Furthermore, the study will investigate what happens if a dependent group is allowed to emphasize their existence by sending a message or to communicate with the independent group of appropriators. Although communication has been shown to be effective in increasing efficiency in other heterogeneity CPR games, the imposition of heterogeneity in interests and participation of a different group may alter the effect of communication.

The experiment has two groups of appropriators. One group has a utility function that follows Walker, Gardner, and Ostrom (1990) and is referred to as a regular or independent appropriator. The other group of appropriators will be called dependent appropriator, because they are affected by the decisions of the independent appropriators. Starting with a regular appropriator, the n number of appropriators, who are given an endowment of e, have the access to the CPR.

Each appropriator makes a decision concerning how much endowment to allocate between a non-CPR and a CPR. The marginal payoff of the non-CPR is constant at w. The payoff of the CPR depends on the group appropriation as well as individual decisions. Let x_i be an appropriation decision of an appropriator i in the CPR, conditioned to $0 \leq x_i \leq e$. The yield from group appropriation is given by a concave production function F that is determined by the group appropriation Σx_i, $F(\Sigma x_i)$, where $F'(0) > w$, $F'(ne) < 0$. This production function returns more at first than the opportunity cost of the non-CPR, but if the level of total appropriation reaches some point, the return decreases at an increasing rate and becomes negative. Thus, Ostrom, Walker, and Gardner (1992, 407) described "(t)he yield from the CPR reaches a *maximum net level* when individuals invest some, but not all, of their appropriations in the CPR (emphasis original)".

The payoff to an appropriator is:

$$u_i = w(e - x_i) + \frac{x_i}{\sum x_i} F\left(\sum x_i\right) \qquad (1)$$ [19]

Equation (1) implies that if a person puts all of the endowment in the safe outside activity, he/she receives the sure value of the endowment times the value per unit of endowment. If a person invests some of the endowment in the outside activity ($e - x_i$) and the remaining part of the endowment in the CPR (x_i), the payoff is composed of the sure return from the outside activity $w(e - x_i)$ and the uncertain return from the CPR. Taking a very simple example, a farmer is endowed with some cash, which he can allocate between a financial market and a CPR pasture.

[19] Later in the experimental design a constant term is added to this function. But this treatment aims to bring the function up into the positive range solely for the actual experiments. It is only to move the level and has no theoretical implications.

The financial market pays a farmer with the sure amount of $w(e - x_i)$. Allocating part of the endowment in a CPR implies, for example, that a farmer buys additional cattle to increase his production. Using more cattle increases his production at first, but as more farmers in a community put more cattle in the CPR, this devastates the grassland as a whole and eventually decreases the production of the group.

Assuming a symmetric game, which implies that every player chooses identical x_i*, there exists a unique symmetric equilibrium. To find this equilibrium, a single player's maximization problem is solved. The first-order condition for equation (1) is:

$$u_i' = -w + \frac{x_i}{\sum x_i} F'\left(\sum x_i\right) + \frac{\sum x_i - x_i}{(\sum x_i)^2} F\left(\sum x_i\right) = 0$$

Assuming that this equilibrium is symmetric and each player (i) invests the same units of endowment x_i*, substituting Σx_i with nx_i* yields:

$$u_i' = -w + \frac{1}{n} F'(nx_i^*) + \frac{n-1}{x_i^* n^2} F(nx_i^*) = 0 \qquad (2)$$

This is the symmetric Nash equilibrium for the baseline CPR game.[20]

The utility function of the dependent appropriators is composed of the returns from a CPR and a non-CPR as with the regular appropriators. Like the regular appropriators, the appropriators of this group are given endowment e,

[20] According to Ostrom, Gardner, and Walker (1994), the symmetric Nash equilibrium is greater than the optimal appropriation but smaller than zero rent appropriation. For more details, see Walker, Gardner, and Ostrom (1991).

which they can invest between the CPR and the non-CPR. The non-CPR returns a payoff at the same constant rate as regular appropriators. The gain from the CPR, however, depends on the regular appropriators' group appropriation in addition to his/her own decision and the decision of the group. Now it is clear why this group of appropriators is referred to as a dependent appropriator. Their utility is dependent on the decisions of the other group of appropriators. In the case of regular appropriators, the CPR function is two-fold. The first effect is created by the quadratic function itself and the second one is by the ratio of an individual allocation over a group allocation. These two-fold effects become three-fold in the dependent appropriator's function. The three-fold function describes the situation where the quality of the CPR allocated to the dependent appropriators is affected by the use of the regular appropriators, and therefore the regular appropriators' decisions as well as a dependent appropriator's own decision and will impact the dependent appropriator's utility gained from the CPR.

Let x_j be an appropriation decision in the CPR, provided $0 \leq x_j \leq e$. The yield from group appropriation is given by $F(\Sigma x_j)$ where $F'(0) > w$, $F'(n_j e) < 0$, the same functional form as appropriators but with different parameters to describe dependent appropriator's interests. Thus, the appropriation in the CPR provides higher returns at the beginning, but once it has reached a maximum level, it provides smaller and smaller returns and eventually a negative payoff as described earlier with a regular appropriator. Using different parameters results in an optimal level of appropriation being located at a different place and changes how fast appropriation increases and decreases. In addition, the regular appropriators' group appropriation negatively affects the dependent appropriators at a constant rate. The difference between the two groups of appropriators appears in the CPR function with parameters for a CPR function and the existence of an influence term of regular appropriators.

The utility of the dependent appropriators is represented by:

$$u_j = w(e - x_j) + \frac{x_j}{\sum x_j} F\left(\sum x_j, \sum x_i\right) \qquad (3)$$

Going back to the earlier example, regular appropriators in a farming industry live upstream in a river while dependent appropriators live downstream and appropriate the river for various purposes. For farmers, allocating their endowment in a river may be regarded as being for agricultural uses like irrigation. For downstream users, it can be applied to industrial uses like a brewery or a paper mill which requires a good quality of water from a river. Another example for downstream users can be found in recreational purposes such as fishing or marine sports, which can cause congestion when the use of a river intensifies. As the amount of water that can be taken from a river is limited, an increase in production does not necessarily lead to more utility. As an upstream farmer increases their group production, the quality and/or the quantity of the water in the river deteriorates, lowering the downstream utility. This is represented by Σx_i in the CPR function. Even if dependent appropriators themselves reach an optimal use of the resources, it does not guarantee the greatest possible utility.

Assuming a symmetric game with x_j fixed at the Nash equilibrium (x_j*), there exists a unique symmetric equilibrium. A single player's maximization problem is to solve the following first-order condition for equation (3):

$$u_j' = -w + \frac{x_j}{\Sigma x_j} F'\left(\sum x_j\right) + \frac{\Sigma x_j - x_j}{\left(\Sigma x_j\right)^2} F\left(\sum x_j\right) = 0$$

Assuming each player (j) invests the same units of endowment x_j*, substituting Σx_j with nx_j* yields:

$$u_i' = -w + \frac{1}{n} F'\left(nx_j^*\right) + \frac{n-1}{x_j^* n^2} F\left(nx_j^*\right) = 0 \qquad (4)$$

This is the symmetric Nash equilibrium for the dependent appropriators.

When given an opportunity, these appropriators can send a message to or initiate communication with regular appropriators to emphasize their existence and to convey their desire. The message is uniform and only the percentage of dependent appropriators in the message who agree to send it varies. Communication is introduced by dependent appropriators only, and when this is executed by one or more of them, regular appropriators have no choice but attend the meeting with the dependent appropriators. This communication is in essence different from the communication in the literature. It is not the same in the sense that it does not necessarily provide a place to discuss an optimal level of CPR appropriation among regular appropriators, which is the sole purpose of communication in a regular setting. In other words, the presence of the other appropriators who seek to minimize CPR appropriation of the regular players is expected to bring some effects of altruism in addition to cooperation into communication. When initiated by dependent appropriators, communication is likely to be a place for them to emphasize the impact of the CPR appropriation by regular players on their utility, which may or may not induce cooperative as well as altruistic actions. Also, these publicity opportunities are to affect the future decision of regular appropriators[21]. In other words, positive x_j implies forward-looking dependent appropriator decisions. Having these opportunities does not affect the Nash equilibrium.

This is a one-shot, repeated game with complete information. It is also a non-cooperative game and a participant makes a decision by himself. When communication is allowed, however, it brings the essence of a cooperative game. All the decisions are anonymous. The decisions of the two groups of appropriators are linked in the time dimension in the sense that the decisions of regular appropriators influence the payoff gained for dependent appropriators. But, each decision of both groups is independent of the previous decision of their own. The baseline experiment with regular appropriators only involves allocation of the resource, namely what and how much to produce. When dependent appropriators join, experiments concern not only allocation but also distribution of the resources between the two groups. It is also assumed that "the natural replacement rate is at least as great as current and foreseeable withdrawal rates", which may not be realistic in considering a CPR dilemma (Gardner, Ostrom, and Walker 1990, 346).

---

[21] The utility function can be intertemporal. The decision made by appropriators in the previous round can affect non-appropriators, which will complicate the Nash equilibrium. This has been left for future analysis.

It is important to note that a Nash equilibrium does not depend on the size of the endowment as long as it is large enough. Although it is generally recognized that a Nash equilibrium predicts well in a CPR game in comparison with a public good game (Andreoni 1995), Ostrom, Walker, and Gardner (1992) pointed out a possible problem with a Nash equilibrium in that it may take a considerable time to stabilize at equilibrium. Bowles (2004) also explained the two drawbacks of the Nash equilibrium. First, it does not justify what players do when out-of-equilibrium. Second, it fails to pin down a unique equilibrium when there are multiple Nash equilibria. Therefore, historical backgrounds and dynamics, including learning, are important to supplement the Nash equilibrium (Bowles 2004). Mason, Sandler, and Cornes (1988) analyzed non-Nash equilibria in the commons dilemma and evaluated them in terms of the optimal number of appropriators. This thesis depends on the Nash equilibrium for a behavioural prediction following the literature of Ostrom, Walker, and Gardner (1992) and Walker, Gardner, and Ostrom (1990, 1991). In addition, adding dependent appropriators may move the equilibrium away from the Nash to an optimal. The results from the experiments will be compared with the Nash equilibrium from the baseline experiment to examine the effects of these new players.

3.2. Experimental design

This study introduces three experimental designs as illustrated in Table 1[22]. Design I involves independent appropriators only and it is the baseline game that is defined in Walker, Gardner, and Ostrom (1990). Design II brings two groups of appropriators together. Independent appropriators make a decision first, followed by dependent appropriators choosing their own allocation level. It is important to note again that the utility of dependent appropriators is dependent on the decision made by independent appropriators as a group as well as their own decisions, while the utility of independent appropriators relies solely on their own decisions and their group's. This design allows dependent appropriators to have some influence on their own utility. The utility of dependent appropriators is not completely dependent on the choices of independent appropriators. Design III is developed to emphasize dependence of dependent appropriators. Design III fixes the allocation of dependent appropriators at the average level given by Design II. In such a situation, the group allocation chosen by independent appropriators decides not only their own utility but also the utility of dependent appropriators in the range fixed by the earlier design. Therefore, in this design independent appropriators make a decision as before, but dependent appropriators are there to be affected by independent appropriators' decisions. This is the design to see whether or not and how the existence of dependent appropriators, in other words a victim, affects the decisions of independent appropriators. Communication and publicity options are exercised here to stress the existence of dependent appropriators and the consequence of independent appropriators' decisions.

[22] The possible instructions for this experiment are attached in the appendix.

Table 1. Three experimental designs

	Design I	Design II	Design III
Who is in the experiment?	Regular appropriators	Regular appropriators Dependent appropriators	Regular appropriators Dependent appropriators
Who makes a decision?	Regular appropriators	Regular appropriators Dependent appropriators	Regular appropriators
Options (communications and publicity)			Allowed

Design I (Baseline Experiment)

The baseline experiment follows the similar experimental design specified by Walker, Gardner, and Ostrom (1990). Allocating the endowment in the safe, outside activity returns 0.01 times the number of units allocated, valued in laboratory dollar. For example, if 10 units of endowment are invested in the outside activity, the return is \$0.10 (laboratory dollar). On the other hand, calculation of the return from CPR is more complicated. Total appropriation in the CPR returns require some units of commodity calculated by the concave production function. Each unit of commodity is valued at \$0.01 (laboratory dollar). The parameters for the baseline experiment are shown in Table 2[23].

As in Walker, Gardner, and Ostrom (1990), a baseline experiment with eight subjects will be conducted. Eight is said to be large enough to induce group

[23] See Walker, Gardner, and Ostrom (1991) for comparison of the experiments with different parametization.

Table 2. Parameters for the Baseline Experiment

Number of subjects	8
Individual endowment (units)	30
CPR appropriation function	$25(\Sigma x_i) - 1/3(\Sigma x_i)^2$
CPR return/ unit of appropriation	\$0.01
Non-CPR return/ unit of endowment	\$0.01
CPR group earnings at maximum	\$4.69
CPR group earnings at Nash equilibrium	\$0.72
CPR group earnings at zero rent	\$0.72

Notes: The table relies heavily on Walker, Gardner, and Ostrom (1990).
The results of calculation are rounded off to two decimal places. The dollars are lab dollars and they are not equivalent to Canadian dollars.

effects[24]. Walker, Gardner, and Ostrom (1990) conducted the experiments with two different endowments, 10 and 25. The experiments proposed in this thesis restrict attention to a higher endowment, because higher endowment experiments have a tendency towards over-appropriation in the CPR, which represents the CPR dilemma more clearly. A CPR appropriation function is quadratic and is defined as $F(\Sigma x_i) = a_i\Sigma x_i - b_i(\Sigma x_i)^2 + c_i$, where a_i =25, b_i =1/3, and c_i =0, which yields a unique symmetric Nash equilibrium. A constant term (=1,250) is added to the utility function to place it in the positive range for the actual experiments. The reason will be clearer when the modification of the experiment is introduced. As Walker, Gardner, and Ostrom (1991) examined the experiments using different parametizations, the results of which are supportive of the same conclusion, this thesis slightly modifies the original parametization introduced by Walker, Gardner, and Ostrom (1990).

[24] Refer to Isaac and Walker (1988) and Isaac, Walker, and Williams (1994) for analysis of the effects of group size on free-riding behaviour in public goods games.

Table 3. Units Produced and Cash Return from Appropriations in the CPR

Endowments Allocated by Group	Units of CPR Appropriated	Total Group Return	Average Return per Endowment	Additional Return per Endowment
30	450	4.50	0.15	0.06
60	300	3.00	0.05	-0.14
90	-450	-4.50	-0.05	-0.34
120	-1,800	-18.00	-0.15	-0.54
150	-3,750	-37.50	-0.25	-0.74
180	-6,300	-63.00	-0.35	-0.94
210	-9,450	-94.50	-0.45	-1.14

Notes: The layout of the table heavily relies on Figure 1 in Walker, Gardner, and Ostrom (1991).
The results of calculation are rounded off to two decimal places.

Table 3 illustrates units appropriated and cash returns from appropriations in the CPR. It should be remembered that, in the CPR, the units of endowment allocated does not equal to the number of units of CPR appropriated. When relatively little endowment is put into the CPR as a group, it returns more units of the CPR to the group. When a group allocates a fairly large amount of the endowment to the CPR, no unit of the CPR is available for appropriation and it even costs the group an extra expense. This is the situation where farmers irrigate too much water from a river and the benefit from expanding the use of the irrigation water exceeds the cost. The first column gives example levels of total appropriation by the group. The second column computes the number of units of CPR appropriated by the corresponding level of appropriation of the first column. The third column multiplies units of CPR in the second column by 0.01 to convert them to a laboratory dollar. The fourth column presents the average cash value per endowment at a given level of appropriation. The final column displays information on the extra value that is earned from additional units of appropriation. For example, taking 30 units of endowment allocated by the group, the group appropriates 450 units of CPR equivalent to the value of \$4.50. The cash return per unit is \$0.15, and additional return per unit is \$0.06. The payoff to each individual depends on how many units an individual invested relative to group appropriation.

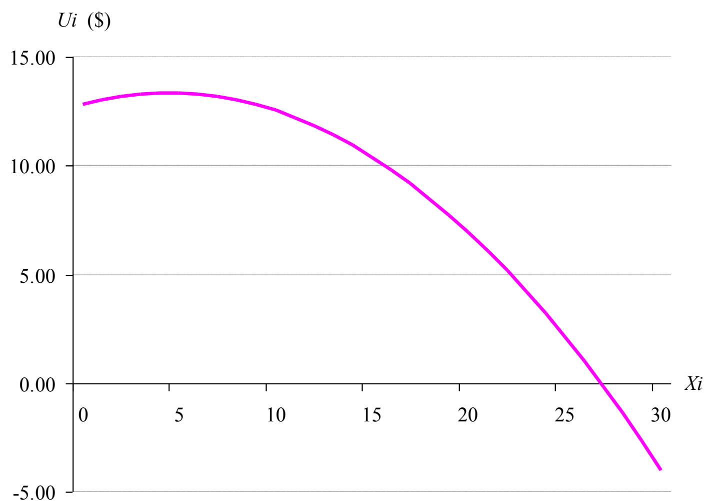
Figure 1 describes the utility function graphically. The graph assumes identical allocation decisions of all the subjects.

As defined in an earlier section, the Nash equilibrium is given by equation (2).

$$u_i' = -w + \frac{1}{n}F'(nx_i^*) + \frac{n-1}{x_i^* n^2}F(nx_i^*) = 0 \qquad (2)$$

The Nash equilibrium for regular appropriators can be obtained by substituting *w*, *n*, and the CPR appropriation function as defined in Table 2. This gives us a Nash equilibrium of 72 units of group endowment in the CPR, which yields a symmetric pure strategy of each subject investing 9 units of endowment. The two other benchmark levels of appropriation in economics are optimum and zero rent. Optimum is a level of appropriation where marginal revenue equals marginal cost, whereas zero rent is a level of appropriation where average revenue equals marginal cost. With these parameters, the optimum is located at 37.5 for group appropriation in the CPR and zero rent is 72, the same as Nash. Although the experiment by Walker, Gardner, and Ostrom (1990) defined the Nash equilibrium as being in between the optimum and the zero rent, in this design the Nash equilibrium is located exactly where economic rents dissipate. Both Nash

Figure 1. Utility Function of Regular Appropriator



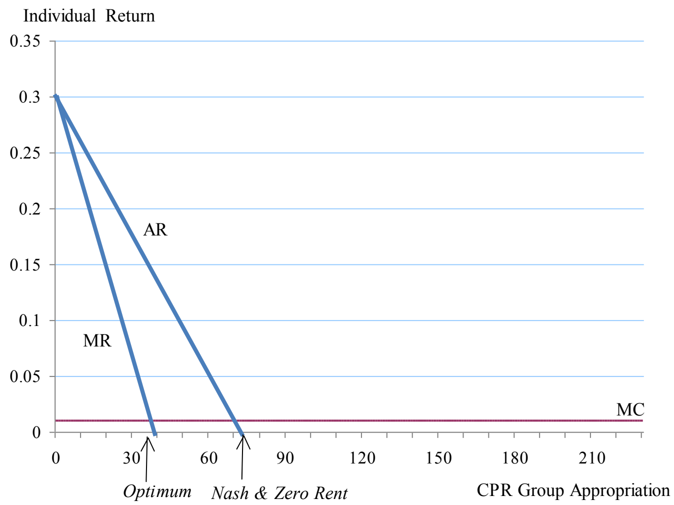
Note: It assumes identical decision of all the subjects.
The whole function is lifted up by the constant (=12.5) and the absolute value is irrelevant.

equilibriums imply over-appropriation of the resources assuming that the optimum is an appropriate level of appropriation. Figure 2 graphically demonstrates this. In theory, the Nash equilibrium predicts over-appropriation. A modification of the design will be attempted to bring this equilibrium closer to the optimum.

Design II (Heterogeneous Experiment)

The standard CPR game involves members with the same interests, thus having the same utility function. So, this experiment is unique because it adds another group of appropriators with a different utility function, whose payoff is dependent on the behaviour of the other group. Adding dependent appropriators may or may not discourage regular ones to over-appropriate in the CPR. This

Figure 2. Theoretical Predictions



Note: The table heavily relies on Walker, Gardner, and Ostrom (1990).
MR = marginal revenue, AR = average revenue, MC = marginal cost

design introduces heterogeneity of appropriators and examines its impact on the behaviour of regular appropriators.

After regular appropriators decide their allocation, a dependent appropriator makes a decision as to how many units of endowment to allocate between a non-CPR and a CPR. Allocating the endowment in the non-CPR returns 0.01 times the number of units allocated valued in cents. On the other hand, the total endowment allocated to the CPR returns some units of appropriation calculated by a concave production function. Each unit of appropriation is valued at $0.01. Table 4 presents the parameters for dependent appropriators as well as regular appropriators.

The number of dependent appropriators is varied to see whether the effects of dependent appropriators on behaviours of regular appropriators change. When the number of dependent appropriators is smaller than regular appropriators, it

Table 4. Parameters for the Heterogeneous Experiment

	Regular appropriator	Dependent appropriator
Number of subjects	8	4, 8
Individual endowment	30	30
CPR appropriation function	$25(\Sigma x_i) - 1/3(\Sigma x_i)^2$	$10.5(\Sigma x_j) - 1/3(\Sigma x_j)^2 + 6976/7 - 10(\Sigma x_i)$
CPR return/ unit of appropriation	\$0.01	\$0.01
Non-CPR return/ unit of endowment	\$0.01	\$0.01
CPR group earnings at maximum	\$4.69	\$4.39*
CPR group earnings at Nash equilibrium	\$0.72	\$0.13*
CPR group earnings at zero rent	\$0.72	\$0.34*

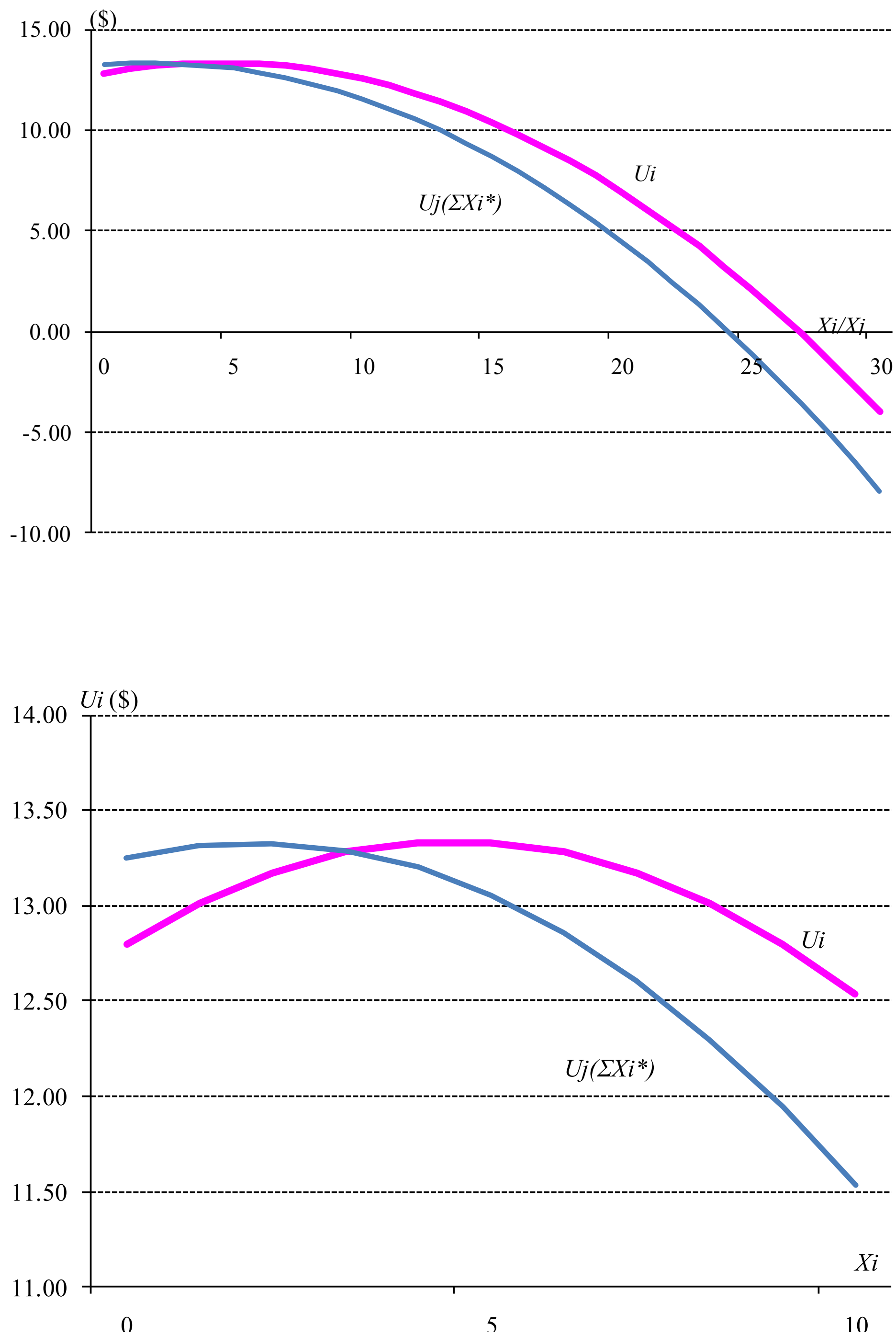
Notes: The layout of the table heavily relies on Walker, Gardner, and Ostrom (1990).
The results of calculation are rounded off to two decimal places. The number with asterisk assumes eight dependent appropriators for calculation and group appropriation of regular appropriators at a Nash equilibrium.

may have a smaller impact. On the other hand, when it is greater, it might affect the result more. The amount of endowment is the same (30) as for regular appropriators. A CPR appropriation function is quadratic and is defined as $F(\Sigma x_j) = a_j\Sigma x_j - b_j(\Sigma x_j)^2 + c_j - d_j\Sigma x_i$, where a_j =10.5, b_j =1/3, c_j=6976/7, and d_j=10, which yields a unique symmetric Nash equilibrium. This function contains a term $d_j\Sigma x_i$ that represents the influence of the behaviour of the regular appropriators on the dependent appropriators. The more endowment the regular appropriators put in the CPR, the less utility the dependent appropriators receive even if they are at an optimum. In other words, the utility that the dependent appropriators can receive is capped by the group allocation by the regular appropriators. This captures the situation where the quality of the CPR in one community is affected by the behaviour in the other community, which imposes a negative externality on the dependent appropriators. Again, the same constant term (=1,250) as is used for the regular appropriators is added to the utility function to place it in the positive range for the actual experiments.

Figure 3 shows the utility functions of dependent appropriators as well as regular appropriators. Both of these functions assume identical decisions by the members in the same group. The utility of dependent appropriators varies depending on their own allocation level, provided that the regular appropriators' decisions are stabilized at the Nash equilibrium. It is important to note that the peaks of both functions are around the same level and the slope of dependent appropriators is steeper than regular appropriator's after the peak.

Table 5 illustrates representative units appropriated and cash returns from appropriation in the CPR by dependent appropriators, provided that the group appropriation of regular appropriators is stabilized at the Nash equilibrium. The same table was provided for regular appropriators. The first column gives different levels of total appropriation by the group. The second column calculates the number of units of CPR appropriation, assuming that the group appropriation of regular appropriators is 72. The third column converts the units of CPR in the second column into laboratory dollars. The fourth column provides the average cash value per endowment at a given level of appropriation. The final column presents the marginal value that is obtained from allocating an additional unit of appropriation. For example, if dependent appropriators allocate 60 units of endowment in total in the CPR, the group appropriates -293 units of CPR valued at $-2.93. The cash return per endowment and additional return per endowment

Figure 3. Utility Functions of Heterogeneous Appropriators



Note: The two graphs show the same functions but in the different scope.

Table 5. Units Produced and Cash Return from Appropriations in the CPR

(Σx_i* fixed)

Endowments Allocated by Group	Units of CPR Appropriated	Total Group Return	Average Return per Endowment	Additional Return per Endowment
15	359	3.59	0.24	-0.02
30	292	2.92	0.10	-0.12
60	-293	-2.93	-0.05	-0.32
90	-1,478	-14.78	-0.16	-0.52
120	-3,263	-32.63	-0.27	-0.72
150	-5,648	-56.48	-0.38	-0.92
180	-8,633	-86.33	-0.48	-1.12
210	-12,218	-122.18	-0.58	-1.32

Notes: The layout of the table heavily relies on Figure 1 in Walker, Gardner, and Ostrom (1991).
The results of calculation are rounded off.

will be $-0.05 and -$0.32 respectively. Negative units of CPR imply that appropriation efforts are so intensive that it degrades the resource. In this situation, the rate of recovery of the resource is below the appropriation rate, and the resource is being depleted. For example, if farmers irrigate more water from a river than the rate of production of water, the result is overappropriation and the farmers do not receive enough revenue to cover the expenses of their irrigation efforts.

Now consider the function in three dimensions. Figure 4 allows the utility function of dependent appropriators to vary with both decisions of dependent and regular appropriators to demonstrate the dynamics of the dependent appropriators' utility function. Again it assumes an identical allocation by all appropriators in the same group. When sliced by any level appropriated by regular appropriators, the function presents concavity as seen in Figure 3. When sliced by dependent appropriators, it shows downward linearity.

Figure 4. Utility Function of Dependent Appropriators

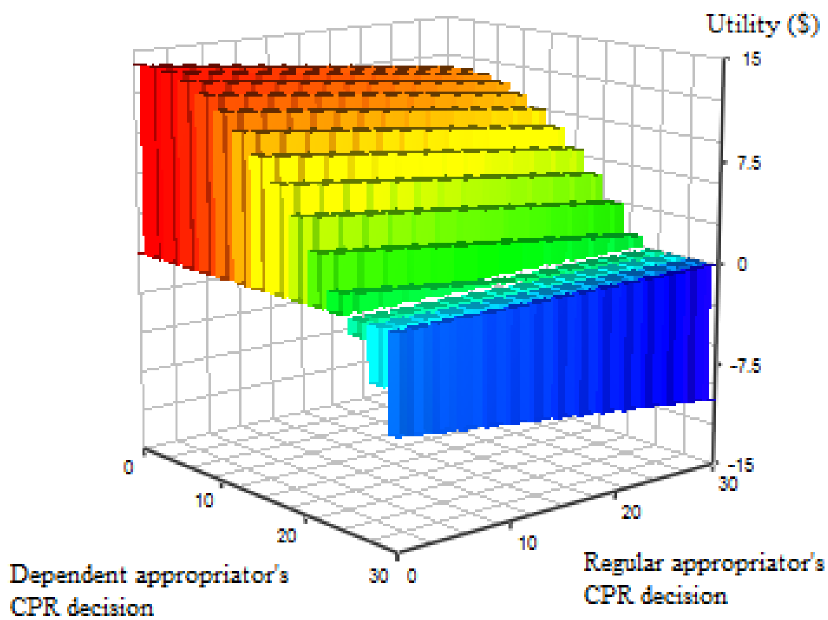


Table 6 is a matrix showing the utility received by dependent appropriators as a function of the number of units of CPR appropriated of the two groups of appropriators. In addition to their own decisions, the dependent appropriators receive the impact of the group appropriation of the regular appropriators. This impact can be considered as an externality, which the dependent appropriators do not have control over. For example, if the regular appropriators allocate 40 units of endowment and dependent appropriators allocate 60 units, these two levels of allocation enable the dependent appropriators to appropriate 27 units of the CPR. This reflects how much the group of regular appropriators appropriated the CPR. The more the regular appropriators

Table 6. Dependent Appropriator's CPR Appropriation Matrix

	Regular Appropriator's Allocation in CPR										
Dependent Appropriator's Allocation in CPR	20	40	60	80	100	120	140	160	180	200	220
20	873	673	473	273	73	-127	-327	-527	-727	-927	-1,127
40	683	483	283	83	-117	-317	-517	-717	-917	-1,117	-1,317
60	227	27	-173	-373	-573	-773	-973	-1,173	-1,373	-1,573	-1,773
80	-497	-697	-897	-1,097	-1,297	-1,497	-1,697	-1,897	-2,097	-2,297	-2,497
100	-1,487	-1,687	-1,887	-2,087	-2,287	-2,487	-2,687	-2,887	-3,087	-3,287	-3,487
120	-2,743	-2,943	-3,143	-3,343	-3,543	-3,743	-3,943	-4,143	-4,343	-4,543	-4,743
140	-4,267	-4,467	-4,667	-4,867	-5,067	-5,267	-5,467	-5,667	-5,867	-6,067	-6,267
160	-6,057	-6,257	-6,457	-6,657	-6,857	-7,057	-7,257	-7,457	-7,657	-7,857	-8,057
180	-8,113	-8,313	-8,513	-8,713	-8,913	-9,113	-9,313	-9,513	-9,713	-9,913	-10,113
200	-10,437	-10,637	-10,837	-11,037	-11,237	-11,437	-11,637	-11,837	-12,037	-12,237	-12,437
220	-13,027	-13,227	-13,427	-13,627	-13,827	-14,027	-14,227	-14,427	-14,627	-14,827	-15,027

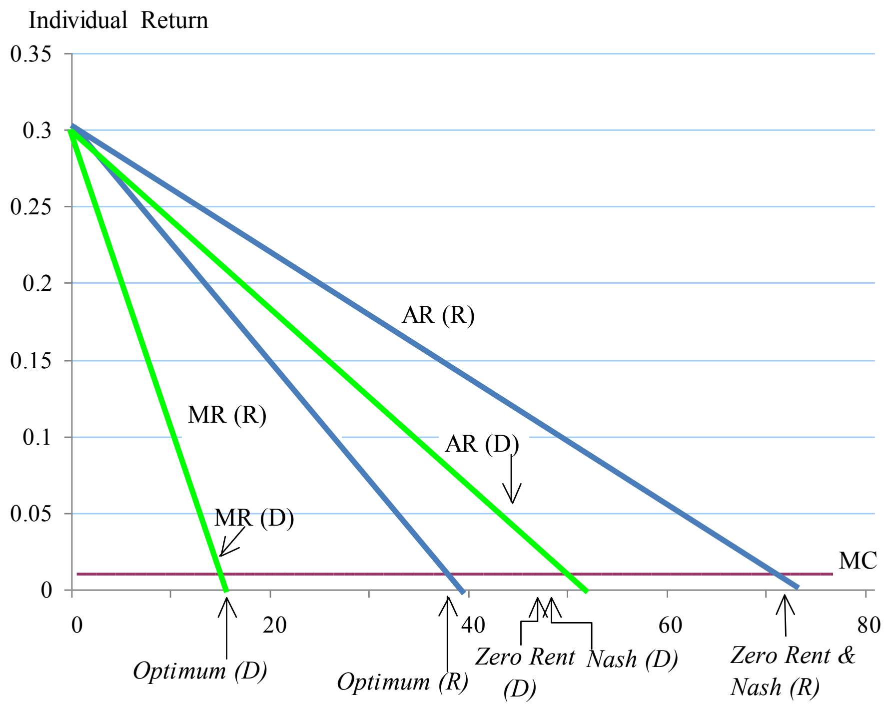
appropriate, the less utility the dependent appropriators receive. This reflects the situation in which upstream farmers irrigate water from a river and downstream users face a reduction in the volume of the water for their use.

Provided that the group appropriation of regular appropriators is fixed at the Nash equilibrium, the Nash equilibrium for dependent appropriators is given by equation (4).

$$u_i' = -w + \frac{1}{n}F'\left(nx_j^*\right) + \frac{n-1}{x_j^* n^2}F\left(nx_j^*\right) = 0 \qquad (4)$$

The Nash equilibrium for dependent appropriators can be obtained by substituting *w*, *n*, and the CPR appropriation function as defined in Table 4. Assume that *n*=8. This gives us a Nash equilibrium of 48 units of group endowment in the CPR, which yields a symmetric pure strategy of each subject investing 6 units of endowment when played by eight subjects. As regular appropriators, an optimum is located at 16 for group appropriation in the CPR and the zero rent allocation is 47, assuming that the group appropriation of regular appropriators is at the Nash

Figure 5. Theoretical prediction

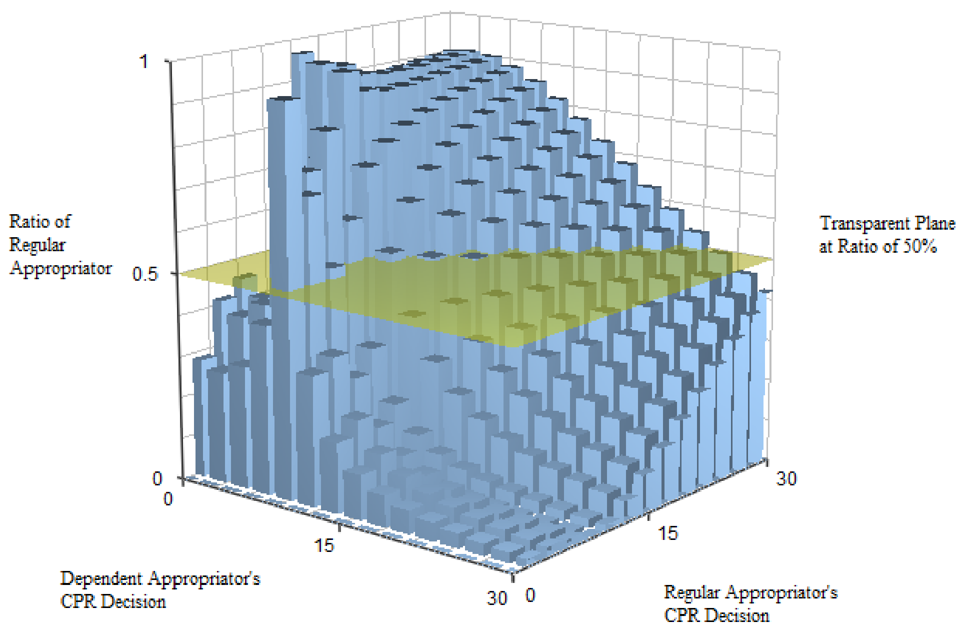


Note: The figure heavily relies on Walker, Gardner, and Ostrom (1990).
MR = marginal revenue, AR = average revenue, MC = marginal cost, D = dependent appropriators,
R= regular appropriators

equilibrium. Both results are rounded off to an appropriate unit. Figure 5 shows the theoretical levels of allocation in comparison with regular appropriators'.

An interesting element of this design is that when dependent appropriators are added, the game involves distributional outcomes as well as allocational ones. Figure 6 illustrates the ratio of regular appropriator's wealth over total wealth created by the two groups of appropriators. It assumes an identical allocation by all appropriators in the same group. When dependent appropriators put a very small amount of endowment in the CPR, it is very likely for regular appropriators to have more bargaining power because of the characteristic of the utility function

Figure 6. Ratio of the Two Appropriators over Total Wealth



that the peak comes at a relatively small level of CPR appropriation. When dependent appropriators put more endowment in the CPR, no matter how much regular appropriators allocate to the CPR, dependent appropriators have more bargaining power because of the steeper slope of the dependent appropriators after the peak. In this situation, dependent appropriators have more bargaining power, but receive a bigger portion of negative returns. When both groups put relatively little endowment in the CPR, their bargaining power shifts from one to the other frequently to reflect the dynamics of their CPR production functions.

A behavioural implication from this design is that there are two communities who share a spatially linked CPR for different purposes. For example, a farming community upstream uses water resources for agricultural purpose while the other community consumes the same water resource in the downstream for other purposes such as recreation or industrial use. If farmers increase the intensity of water for irrigation to increase agricultural production, this could result in a reduction of water available to the other community for recreational use. Another example would be when the upstream community increases the use of pesticides or fertilizers, the quality of water that the downstream community receives may be lowered or even polluted. The downstream community appropriates the CPR given the condition set by the upstream community, such as a reduced amount of water or low quality of water. In other words, if the status quo is defined as no appropriation by the upstream community, the difference in water quality brought about by the upstream community's appropriation can be considered as an externality imposed on the downstream community.

Design III (Heterogeneous Experiment)

Heterogeneity of appropriators is re-examined, but in this design the other group of appropriators are victims, whose utility is completely dependent on other appropriators. Dependent appropriators get their utility without making any decisions and have no control. Design III fixes the allocation level of dependent appropriators at the average allocation obtained by Design II. As before, a regular appropriator makes an allocation decision, which also decides the utility of the dependent appropriators. Although their own decisions from the previous design determine the range in which their utility can be, the decisions made by regular appropriators in this experiment finalise the utility of dependent appropriators in this experiment. If adding this dependent group discourages the regular group from over-appropriation of the CPR, it can be said that altruism is an influential factor halting degradation of the CPR. In order to emphasise the dependence of the dependent appropriators, dependent appropriators are provided with the two options for publicity and communication, which will be detailed later.

The parameters for the design are the same as the previous design except for a change in the CPR appropriation function of dependent appropriators. The sum of their allocation decisions (Σx_j) is replaced with the average level from the previous design, which makes the function downward and linear (Table 7).

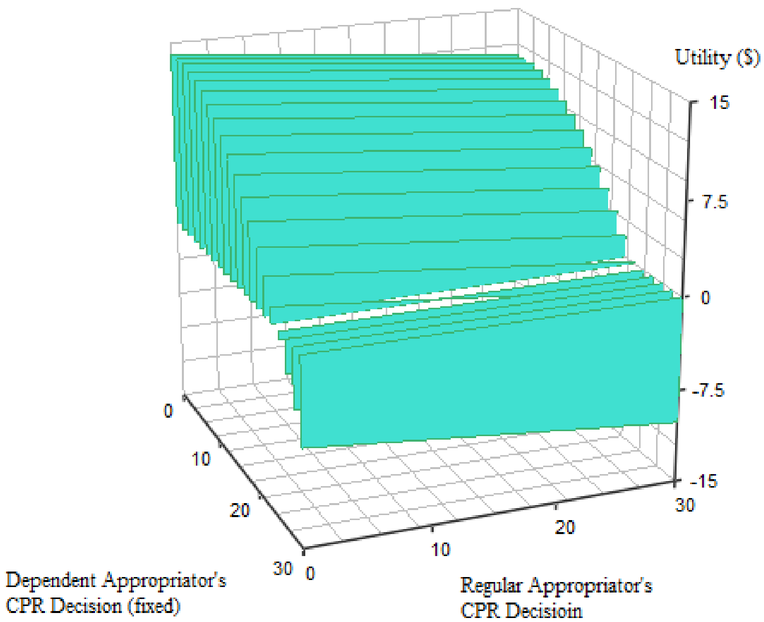
Figure 7 illustrates the function. The dependent appropriator's CPR decision is fixed at levels between 0 and 30. As regular appropriators put more endowment into the CPR, this results in lower utility being received by the dependent appropriators, no matter where their allocation level is fixed. Figure 8 shows the utility function of dependent appropriators when their allocation level is fixed at the Nash equilibrium.

Table 8 shows units appropriated and cash returns from appropriations in the CPR when their allocation level is fixed at the Nash equilibrium. As before, the first column provides example levels of total appropriation by the regular group. The second column computes the number of units of CPR appropriated by the corresponding level of appropriation of the first column. The fourth column presents the average cash value per endowment of the dependent group. The final

Table 7. Dependent Appropriator's CPR Appropriation Function

Design II	Design III
$7.2(\Sigma x_j) - 1/3(\Sigma x_j)^2 + 11050 - 10(\Sigma x_i)$	$-10(\Sigma x_i)$ + Constant

Figure 7. Utility Function of Dependent Appropriators



column displays information on the marginal value that is earned from an additional unit of appropriation. As the function is linear, the average value decreases as the allocation increases at a constant rate implied by the fourth and fifth column. For example, taking 30 units of endowment allocated by the regular group, it allows the dependent group to appropriate 748 units of CPR valued at \$7.48. The cash return per unit is \$0.19, and additional return per unit is -\$0.09.

Figure 8. Utility Function of Dependent Appropriator (Σx_j^* fixed)

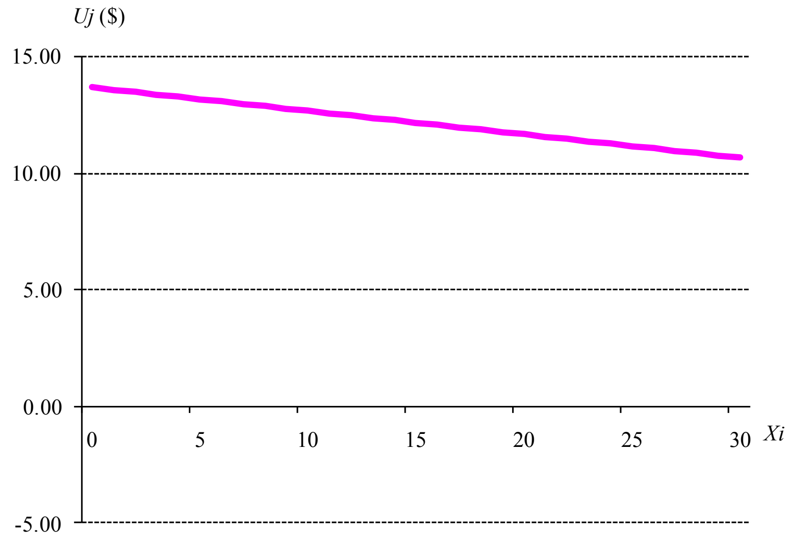


Table 8. Units appropriated and cash return from appropriations in the CPR

(Σx_j^* fixed)

Endowment Allocated by Group	Units of CPR Appropriated	Total Group Return	Average Return per Endowment	Additional Return per Endowment
30	748	7.48	0.19	-0.09
60	448	4.48	0.11	-0.09
90	148	1.48	0.04	-0.09
120	-152	-1.52	-0.04	-0.09
150	-452	-4.52	-0.11	-0.09
180	-752	-7.52	-0.19	-0.09
210	-1,052	-10.52	-0.26	-0.09

Notes: The layout of the table relies heavily on Figure 1 in Walker, Gardner, and Ostrom (1991). The results of calculation are rounded off to two decimal places. Per endowment means per endowment of dependent appropriator.

A constant term is added to the function to move the function into the positive range. The decisions of dependent appropriators are fixed at the average level from the previous design, and the option to vary the investment each round to secure a positive profit is not available in this design. When most of the range of the function is situated below the x-axis, it is possible for dependent appropriators to make a negative profit.

In addition, in this design dependent appropriators are provided with two options: publicity and communication. The publicity option allows the appropriators to deliver a message to the regular appropriators. The message could be defined as follows:

This message is to inform you that (*) % of dependent players are dissatisfied with your group investment in the CPR. We would like to ask all of you to reduce the amount of endowment put into CPR. Please make your decision that takes this notice into account.[25]

This message is designed to emphasize the existence of victims, who are affected by someone else's actions. What this message is expected to do is to remind regular appropriators that their appropriation in the CPR has been harming other people, who have no influence over the regular appropriator's decision. While the regular appropriators are not bound by the message, conscience may motivate them to reduce the appropriation in the CPR. This option is expected to reveal cooperation resulting from altruism.

The other option, communication, is very similar to the one introduced by Walker, Gardner, and Ostrom (1994) and Ostrom, Walker, and Gardner (1992). The difference is that a dependent appropriator, who was not in their papers,

[25] The words highlighted in gray will be replaced with more neutral words in actual experiments such as player B for dependent players and market 2 for CPR.

initiates communication and participates in discussion. Communication in Ostrom, Walker, and Gardner (1994) involved the members in the group only, and communication was a means for them to discuss how they could improve the return from the CPR and how much of their endowment each of them should invest. Participation of dependent appropriators may hinder or encourage cooperation among regular appropriators.

This design implies that one community appropriates the CPR, but the other community does not. The community that does not appropriate the CPR, however, does care about the CPR. In other words, this design makes one community an appropriator and the other a victim of the behaviour of the appropriators. The victims are there to be affected by the behaviour of others. For instance, this victim role can be regarded as an environmentalist. An environmentalist is usually not an appropriator and thus does not have control over the CPR. What they care about is the healthy existence of the CPR and its quality. The more the CPR is appropriated, the lower the quality of the CPR becomes, and the less utility environmentalists receive. The CPR returns for group appropriation for regular appropriators are different from the returns received by dependent appropriators. For regular appropriators, the return function is quadratic and, as described in the earlier design, their returns increase at a decreasing rate prior to their peak and decrease after the peak. For dependent appropriators, on the other hand, their returns decrease at a constant linear rate as the regular appropriators increase the group appropriation of the CPR. This difference results from the difference in perspectives and interests. The regular appropriators CPR obtain a maximum profit when others in their group appropriate relatively small amounts. The victims receive their greatest utility when the CPR is left intact. The experiments will examine the impact of the existence of this third party player on the behaviour of appropriators. The two options are available to emphasize their existence and to make a greater impact on regular appropriators.

4. CONCLUSION

The thesis studies efficient institutions for a sustainable use of a CPR and provides an analytical framework using an experimental method. Particularly, modification of the CPR game introduced by Walker, Gardner, and Ostrom (1990) is made to describe the situation where the use of a CPR by a group of appropriators imposes a negative externality on the other group. This modification is intended to test whether having a victim group can induce altruistic behaviours by the other group. Communication among the groups, following Ostrom, Walker, and Gardner (1992), is allowed to encourage the altruism.

According to the literature, the baseline CPR game showed no tendency of stabilizing at the unique Nash equilibrium at an individual level (Walker, Gardner, and Ostrom 1990)[26]. It should be noted, however, that the time required to stabilize at a Nash equilibrium could be quite long (Walker, Gardner, and Ostrom 1990). The results from the literature also suggest that individuals' decisions failed to achieve a Pareto optimal solution and communication was effective in increasing efficiency. Imposition of heterogeneity in interests may alter the robustness of these results. First, the mere existence of dependent appropriators may increase efficiency of appropriation without relying on communication. The utility of dependent appropriators decreases as group appropriation by regular appropriators increases. If regular appropriators care about the dependent appropriators who are at the mercy of regular appropriators,

[26] For the argument of robustness of a Nash equilibrium, see Bowles (2004). Andreoni (1995) argued a better prediction of a Nash equilibrium in a common-pool resource game, comparing the one in a public good game. Nash's relevancy in a CPR game may not have been established.

they may decrease their appropriation of the CPR as a group, which results in an increase in efficiency if their group appropriation was above the Pareto optimal.

The role of communication in a heterogeneous CPR game may be different from the one observed in a homogeneous game. In a homogeneous game, communication is a place for regular appropriators to discuss an appropriate level of individual appropriation and to prevent free-riding behaviour. Participation by dependent appropriators may bring down an appropriate level of individual appropriation below the Pareto optimal and may appeal to altruism of regular appropriators to justify that level. If so, the publicity option may be good enough as a means of communication to demand regular appropriators to reduce their appropriation of the CPR. In such a case, communication is not a means to induce cooperative actions among appropriators. Rather, it is a means for dependent appropriators who do not have complete control over their utility.

The heterogeneity represented in this experiment also involves the potential for altruistic behaviour by regular appropriators. Cárdenas and Ostrom (2004) found empirical support for the situation where individuals' decisions involving the use of the CPR may be affected not only by the structure of the game but also by the characteristics of the individuals. Yet, the literature demonstrated that altruism has not been successful in explaining human behaviour (Velez, Stranlund, and Murphy 2009; Levine 1998; Croson 2007). Andreoni and Miller (1996) argued that altruism is a fundamental factor of choice, but concluded that altruism might be influenced by other aspects such as fairness and reciprocity. Using examples from the ultimatum and public goods games, Levine

(1998) examined the economic theory that individuals are selfish. He attributed the theory's inability to explain these games to "a failure of the assumption of selfish players" (Levine 1998, 594). One explanation he proposed was that players considered other players' payoffs as well as their own when they made a decision. In fact, he showed that a model of altruism[27] partly explained the results of the experiment of the public goods game. The experiments in the thesis implicitly test the claim that altruism can increase efficiency in use of the CPR by encouraging a reduction of CPR appropriation in a commons dilemma.

Further research is needed. There are some important features in terms of experimental design which are neglected in this study. An empirical backup of the experimental design can be incorporated. The relationship between water use by the upstream farmers and its impact on the payoff function of the downstream residents may involve a scientific or empirical examination. Case studies can be helpful. Furthermore, the experiment in this thesis assumes complete information, maximization of profits, and no capacity for subjects to change the institution. As Ostrom (2002b) pointed out, in some cases appropriators are capable of adjusting the institution that they are influenced by, which is one of the attributes for sustainable use of a CPR. In order to induce cooperative actions among them, appropriators themselves can improve the institution to achieve efficient and enduring use of a CPR. Depending on the characteristics of participants, or in other words the problems they face, the introduction of communication,

[27] The parameter for the model was allowed to take a value for spiteful as well as altruistic behaviour.

identifiability of participants' decisions, or the imposition of rewards or sanctions can be chosen by participants.

Another important limitation is found in that the game is not intertemporal, thus not repeated. In real life the situation modeled in this thesis could be better represented by a repeated game. The upstream farmers are likely to make similar water-use decisions every season, and the downstream residents are likely to continue to be affected by their decisions. When the game is repeated, a concern for reputation and an importance of interactions between subjects may influence a decision making process even more. Communication builds a sense of being part of a community, and people start to care about how they are perceived by the community. This can affect equilibrium calculations of the upstream farmers, and concerns for reputation may induce cooperative behaviours among them.

As Ciriacy-Wantrup (1968) claimed, conservation of a resource is an intertemporal issue. Current appropriation affects the capacity for appropriation in the future. In the design for the experiment proposed in this thesis, each decision is independent of decisions made in the past and so is the payoff. Current utility is not influenced by the decisions of the past. This design allows for the decisions of regular appropriators to influence the utility of dependent appropriators, which enables the game to have some time dimension. But it does not represent the relationship between the decision made in one period and the utility to be obtained in a future period. This makes the game simple, and somewhat un realistic. For example, when trees in a forest are excessively harvested during one period, trees available to the next period will be limited and inevitably this narrows the decision space for an appropriator. When the issue is how to achieve the optimal use of a CPR over time, the introduction of the time dimension to the game is critical. They are left to future study.

References

Andreoni, James. 1989. Giving with Impure Altruism: Applications to Charity and Ricardian Equivalence. *The Journal of Political Economy* 97 (6):1447-1458.

———. 1990. Impure Altruism and Donations to Public Goods: A Theory of Warm-Glow Giving? *Economic Journal* 100 (401):464-477.

———. 1995. Warm-Glow Versus Cold-Prickle: The Effects of Positive and Negative Framing on Cooperation in Experiments. *The Quarterly Journal of Economics* 110 (1):1-21.

Andreoni, James, and John H. Miller. 1996. Giving according to GARP: an experimental study of rationality and altruism. *University of Wisconsin, Madison, WI*.

Baland, Jean-Marie, and J. P. Platteau. 1996. *Halting degradation of natural resources : is there a role for rural communities?* Rome: Food and Agriculture Organization of the United Nations.

Berkes, Fikret. 1992. *Common property resources : ecology and community-based sustainable development*. London: Belhaven Press.

Bixenstine, V. Edwin, Clifford A. Levitt, and Kellogg V. Wilson. 1966. Collaboration among six persons in a Prisoner's Dilemma game. *Journal of Conflict Resolution* 10 (4):488-496.

Bowles, Samuel. 2004. *Microeconomics : behavior, institutions, and evolution*, *The roundtable series in behavioral economics*. New York: Russell Sage.

Brechner, Kevin C. 1977. An experimental analysis of social traps. *Journal of Experimental Social Psychology* 13 (6):552-564.

Bromley, Daniel W. 1992. The commons, common property, and environmental policy. *Environmental and Resource Economics* 2 (1):1-17.

———. 1997. Property regimes in environmental economics. In *The international yearbook of environmental and resource economics 1997/1998: a survey of current issues*, edited by H. Folmer and T. Tietenberg. Cheltenham, UK: Edward Elgar.

Bromley, Daniel W., and David Feeny. 1992. *Making the commons work : theory, practice, and policy*. San Francisco, Calif.: ICS Press.

Caldwell, Michel D. 1976. Communication and sex effects in a five-person Prisoner's Dilemma Game. *Journal of Personality and Social Psychology* 33 (3):273-280.

Cárdenas, Juan-Camilo, and Elinor Ostrom. 2004. What do people bring into the game? Experiments in the field about cooperation in the commons. *Agricultural Systems* 82 (3):307-326.

Chamberlin, Edward H. 1948. An Experimental Imperfect Market. *The Journal of Political Economy* 56 (2):95-108.

Chan, Kenneth S., Stuart Mestelman, Robert Moir, and R. Andrew Muller. 1999. Heterogeneity and the Voluntary Provision of Public Goods. *Experimental Economics* 2 (1):5-30.

Ciriacy-Wantrup, S. V. 1968. *Resource conservation: economics and policies*. Third ed. Berkeley: University of California, Division of Agricultural Sciences, Agricultural Experiment Station.

Ciriacy-Wantrup, S.V., and Richard C Bishop. 1975. Common Property as a Concept in Natural Resources Policy. *Natural Resources Journal* 15:713-727.

Coase, R. H. 1960. The Problem of Social Cost. *Journal of Law and Economics* 3:1-44.

Crabbé, Philippe J. 1983. The contribution of L. C. Gray to the economic theory of exhaustible natural resources and its roots in the history of economic thought. *Journal of Environmental Economics and Management* 10 (3):195-220.

Croson, Rachel T. A. 2007. Theories of Commitment, Altruism and Reciprocity: Evidence from Linear Public Goods Games. *Economic Inquiry* 45 (2):199-216.

Cummings, Ronald G., and Oscar R. Burt. 1969. The Economics of Production from Natural Resources: Note. *The American Economic Review* 59 (5):985-990.

Davis, Douglas D., and Charles A. Holt. 1992. *Experimental economics*. Princeton, N.J.: Princeton University Press.

Dawes, Robyn M., Jeanne McTavish, and Harriet Shaklee. 1977. Behavior, communication, and assumptions about other people's behavior in a commons dilemma situation. *Journal of Personality and Social Psychology* 35 (1):1-11.

Dolsak, Nives, and Elinor Ostrom. 2003. *The commons in the new millennium : challenges and adaptation*. Cambridge, Mass.: MIT Press.

Edney, Julian J., and Christopher S. Harper. 1978. Heroism in a resource crisis: A simulation study. *Environmental Management* 2 (6):523-527.

Falk, Armin, Ernst Fehr, and Urs Fischbacher. 2005. Driving Forces behind Informal Sanctions. *Econometrica* 73 (6):2017-2030.

Fisher, Ann, William J. Wheeler, and Rami Zwick. 1993. Experimental Methods In Agricultural And Resource Economics: How Useful Are They? *Agricultural and Resource Economics Review* 22 (2).

Gardner, R. O. Y., Elinor Ostrom, and James M. Walker. 1990. The Nature of Common-Pool Resource Problems. *Rationality and Society* 2 (3):335-358.

Gordon, H. Scott. 1954. The Economic Theory of a Common-Property Resource: The Fishery. *Journal of Political Economy* 62 (2):124.

Gordon, Richard L. 1966. Conservation and the Theory of Exhaustible Resources. *The Canadian Journal of Economics and Political Science / Revue canadienne d'Economique et de Science politique* 32 (3):319-326.

———. 1967. A Reinterpretation of the Pure Theory of Exhaustion. *The Journal of Political Economy* 75 (3):274-286.

Gray, Lewis Cecil. 1914. Rent Under the Assumption of Exhaustibility. *The Quarterly Journal of Economics* 28 (3):466-489.

Hackett, Steven C. 1992. Heterogeneity and the Provision of Governance for Common-Pool Resources. *Journal of Theoretical Politics* 4 (3):325-342.

Hackett, Steven, Edella Schlager, and James Walker. 1994. The Role of Communication in Resolving Commons Dilemmas: Experimental Evidence with Heterogeneous Appropriators. *Journal of Environmental Economics and Management* 27 (2):99-126.

Hamburger, Henry. 1973. N-Person Prisoner's Dilemma. *Journal of Mathematical Sociology* 3 (1):27-48.

Hardin, Garrett. 1968. The Tragedy of the Commons. *Science* 162 (3859):1243-1248.

Hardin, Russell. 1971. Collective action as an agreeable n-prisoners' dilemma. *Behavioral Science* 16 (5):472-481.

———. 1982. *Collective action*. Baltimore: Johns Hopkins University Press.

Hotelling, Harold. 1931. The Economics of Exhaustible Resources. *The Journal of Political Economy* 39 (2):137-175.

Isaac, R. Mark, and James M. Walker. 1988. Group Size Effects in Public Goods Provision: The Voluntary Contributions Mechanism. *Quarterly Journal of Economics* 103 (1):179-199.

Isaac, R. Mark, James M. Walker, and Arlington W. Williams. 1994. Group size and the voluntary provision of public goods : Experimental evidence utilizing large groups. *Journal of Public Economics* 54 (1):1-36.

Jerdee, Thomas H., and Benson Rosen. 1974. Effects of opportunity to communicate and visibility of individual decisions on behavior in the common interest. *Journal of Applied Psychology* 59 (6):712-716.

Jevons, William Stanley, and Alfred William Flux. 1906. *The coal question; an inquiry concerning the progress of the nation, and the probable exhaustion of our coal-mines*. Third ed. London: Macmillan Co.

Johnson, Ronald N., and Gary D. Libecap. 1982. Contracting Problems and Regulation: The Case of the Fishery. *The American Economic Review* 72 (5):1005-1022.

Jorgenson, Dale O., and Anthony S. Papciak. 1981. The effects of communication, resource feedback, and identifiability on behavior in a simulated commons. *Journal of Experimental Social Psychology* 17 (4):373-385.

Kagel, John H., and Katherine Willey Wolfe. 2001. Tests of Fairness Models Based on Equity Considerations in a Three-Person Ultimatum Game. *Experimental Economics* 4 (3):203-219.

Kelley, Harold H., and Janusz Grzelak. 1972. Conflict between individual and common interest in an N-person relationship. *Journal of Personality and Social Psychology* 21 (2):190-197.

Levine, David K. 1998. Modeling Altruism and Spitefulness in Experiments. *Review of Economic Dynamics* 1 (3):593-622.

Mason, Charles F., Todd Sandler, and Richard Cornes. 1988. Expectations, the commons, and optimal group size. *Journal of Environmental Economics and Management* 15 (1):99-110.

Messick, David M., and Carol L. McClelland. 1983. Social Traps and Temporal Traps. *Pers Soc Psychol Bull* 9 (1):105-110.

Naidu, Sirisha C. 2005. Heterogeneity and Common Pool Resources: Collective Management of Forests in Himachal Pradesh, India. In *Working Paper*: Department of Resource Economics, University of Massachusetts, Amherst.

Olson, Mancur. 1965. *The logic of collective action; public goods and the theory of groups*, *Harvard economic studies, v. 124*. Cambridge, Mass.: Harvard University Press.

Ostrom, Elinor. 1990. *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge: Cambridge University Press.

———. 2002a. Common-Pool Resources and Institutions: Toward a Revised Theory. In *Handbook of agricultural economics. Volume 2A*, edited by B. L. Gardner and G. C. Rausser: Amsterdam: Elsevier Science.

———. 2002b. Reformulating the commons. *Ambiente & sociedade*:5-25.

Ostrom, Elinor, Roy Gardner, and James Walker. 1994. Communication in the the Commons. In *Rules, games, and common-pool resources*, edited by E. Ostrom, R. Gardner and J. Walker. Ann Arbor: University of Michigan Press.

———. 1994. *Rules, games, and common-pool resources*. Ann Arbor: The University of Michigan Press.

Ostrom, Elinor, James Walker, and Roy Gardner. 1992. Covenants With and Without a Sword: Self-Governance Is Possible. *The American Political Science Review* 86 (2):404.

Plott, Charles R. 1991. Will Economics Become an Experimental Science? *Southern Economic Journal* 57 (4):901-919.

Poteete, Amy R., Marco Janssen, and Elinor Ostrom. 2010. *Working together : collective action, the commons, and multiple methods in practice*. Princeton, NJ: Princeton University Press.

Sarker, Ashutosh, Helen Ross, and Krishna K. Shrestha. 2008. A common-pool resource approach for water quality management: An Australian case study. *Ecological Economics* 68 (1-2):461-471.

Schnier, Kurt Erik. 2009. Spatial externalities and the common-pool resource mechanism. *Journal of Economic Behavior & Organization* 70 (1-2):402-415.

Scott, Anthony. 1955a. *Natural resources; the economics of conservation*. Toronto: McClelland and Stewart.

———. 1955b. The Fishery: The Objectives of Sole Ownership. *The Journal of Political Economy* 63 (2):116-124.

Smith, Vernon L. 1968. Economics of Production from Natural Resources. *The American Economic Review* 58 (3):409-431.

Smith, Vernon L. . 1962. An Experimental Study of Competitive Market Behavior. *The Journal of Political Economy* 70 (2):111-137.

———. 1964. Effect of Market Organization on Competitive Equilibrium. *The Quarterly Journal of Economics* 78 (2):182-201.

Van Soest, Daan, and Jana Vyrastekova. 2006. Peer enforcement in CPR experiments: the relative effectiveness of sanctions and transfer rewards, and the role of behavioural types. In *Using experimental methods in* *environmental and resource economics*, edited by J. A. List. Cheltenham, UK: Edward Elgar.

Velez, Maria Alejandra, John K. Stranlund, and James J. Murphy. 2009. What motivates common pool resource users? Experimental evidence from the field. *Journal of Economic Behavior & Organization* 70 (3):485-497.

Walker, James M., and Roy Gardner. 1992. Probabilistic Destruction of Common-pool Resources: Experimental Evidence. *The Economic Journal* 102 (414):1149-1161.

Walker, James M., Roy Gardner, and Elinor Ostrom. 1990. Rent Dissipation in a Limited-Access Common-Pool Resource: Experimental Evidence. *Journal of Environmental Economics and Management* 19 (3):203-211.

———. 1991. Rent Dissipation and Balanced Deviation Disequilibrium in Common Pool Resources: Experimental Evidence. In *Game Equilibrium Models II: Methods, Morals, and Markets*, edited by R. Selten. Berlin: Springer-Verlag.

Appendix: Instructions for the Experiment

The preliminary instructions below relies on the instructions provided by Walker, Gardner, and Ostrom (1990).

Instructions for the experiment

Thank you for participating in the experiment today. We ask that you do not communicate with other participants during the experiment unless instructed otherwise, and make decisions by yourself. Please raise your hands at any time if you have any questions.

Describing the experiment

The experiment in which you are participating is comprised of a sequence of market periods and there are three different experimental designs. In each market period of all the experiments, player A will be asked to make a series of the same investment decisions. Player B will be asked to participate in the two of the three designs. In each market period of one design, player B will be asked to make a series of investment decisions as player A, but in each period of the other experiment, player B will be asked to make a different decision. There are 8 persons in total who will be acting as A and 8 persons who will be acting as B.

Each period player A and player B will be provided with $12.50 to secure your profits. Thus, it is not possible for you to make a negative profit unless you choose to do so.

Each period player A and B will be also allocated 30 units of endowment. Total endowment for each group is 240 units. Player A will decide each market period how he/she wishes to invest his/her endowment between two investment opportunities. Player B will do the same in one experiment. In the other experiment player B will decide whether or not to exert some effort that may potentially influence player A's decisions.

	Design I	Design II	Design III
Participants	Player A	Player A and B	Player A and B
Decision type	Investment decision	Investment decision	Player A: investment decision Player B: different decision

All of the decisions will be anonymous. The instructions, which follow, will describe the investment opportunities for player A and B, and the other actions available to player B.

Design I (Instructions for Player A)

Player A's total earnings comprise return from market 1 and return from market 2. The return on investment in market 1 can be explained rather simply. Each unit invested in market 1 yields player A a return of one unit of commodity 1. Each unit of commodity 1 has a value of $ 0.01.

Thus for example:
1) If player A invested 3 units in market 1, he/she would receive 3 units of commodity 1 valued at $ 0.03.
2) If player A invested 6 units in market 1, he/she would receive 6 units of commodity 1 valued at $ 0.06.

IN SUMMARY:
A) Each additional unit invested in market 1 yields an additional cash return of $ 0.01.
B) Player A is receiving $ 0.01 per unit invested in market 1.

Up until now, if you have any questions, please do not hesitate to ask now.

INVESTMENT RETURN: MARKET 2

The return on investment in Market 2 is a bit more complicated to explain. As in market 1, units invested in Market 2 yield units of commodity 2. Each unit of commodity 2 has a value of $0.01. However, the units of commodity 2 player A receive for investment in Market 2 is dependent upon how many units other members of the group invest in market 2. In Market 2 the return player A receives on investments depends on the amount he/she invests as well as the amount all others in the group invest.

For example:
1) If the group as a whole invested 50 units in market 2 in a period in which you invested 6 units, you would receive 12% (6/50) of the units of commodity 2 earned by the group.
2) If the group as a whole invested 150 units in market 2 in a period in which you invested 12 units, you would receive 8% (12/150) of the units of commodity 2 earned by the group.

In summary, each player A receives a percentage of the total group return dependent upon what share of the total group investment he/she made.

Up until now, if you have any questions, please do not hesitate to ask now.

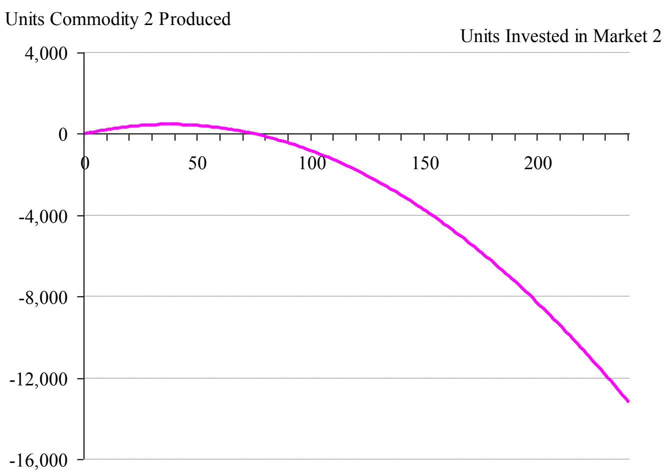
Let us define x as the total number of units invested in market 2 by all members in a group. We can calculate the number of units of commodity 2 produced as:

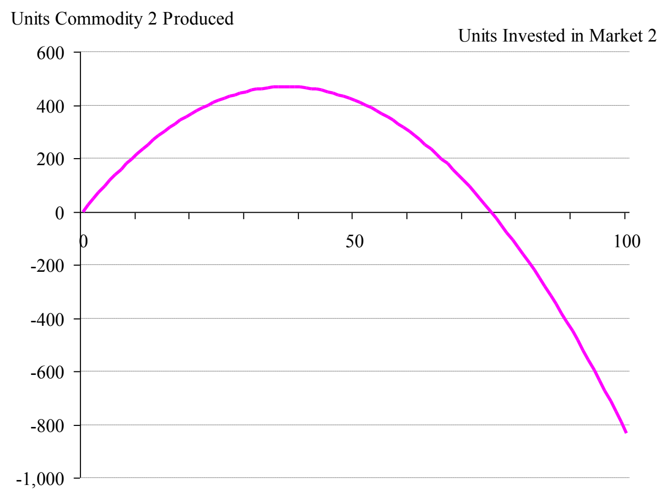
units of commodity 2 = $ax-bx^2$

where: a=25 b=1/3

Examples:
1) if total units invested = 30 then total units of commodity 2 = 450.
2) if total units invested = 150 then total units of commodity 2 = -3,750.

The following figures show the range the above function can take. The figure on the left ranges from zero to 240, and the one on the right from zero to 100.





UNITS PRODUCED AND CASH RETURN FROM INVESTMENTS IN MARKET 2

Units Invested by Group	Units of Commodity 2 Produced	Total Group Return	Average Return per Unit	Additional Return per Unit Invested
30	450	4.50	0.15	0.06
60	300	3.00	0.05	-0.14
90	-450	-4.50	-0.05	-0.34
120	-1,800	-18.00	-0.15	-0.54
150	-3,750	-37.50	-0.25	-0.74
180	-6,300	-63.00	-0.35	-0.94
210	-9,450	-94.50	-0.45	-1.14

commodity 2 value per unit = $ 0.01

The table shown above displays information on investments in market 2 at various levels of total group investment. A similar table will be available during the experiment. Let's talk about the meaning of the information given in the table.

The first column "Units Invested by the Group" gives example levels of total investment by the group in Market 2. These are examples to give you a sense of the payoff from Market 2 at various levels. Actual return from Market 2 will depend on exactly how many units your group invests in Market 2.

The second column labeled "Units of Commodity 2 Produced" gives the level of units of commodity 2 produced for each level of group investment. For example, if 120 units were invested, there would be –1,800 units of commodity 2 produced.

The third column labeled "Total Group Return" displays the actual payoff to the entire group for a given level of group investment. For example, if the group invested 90 tokens, the total laboratory dollar payoff to the group from investing in Market 2 would be $-4.50.

The fourth column, labeled "Average Return per Unit," displays the laboratory dollar value at any level of investment, but on a per unit (average) basis. Thus, if the group invests 90 tokens, the average return per token in Market 2 is $-0.05.

The final column, labeled "Additional Return per Unit Invested'", displays information on the extra value that is earned from additional units invested. Thus, when the level of group investment is at 90 units, the value of investing additional units into Market 2 is approximately $-0.34 per token.

Up until now, if you have any questions, please do not hesitate to ask now.

IN SUMMARY:
1) The return each player A receives from units invested in market 2 depends on how many units he/she invests and how many units other group members invest in market 2.

2) Each player A will not know how many units other group members have invested in market 2 when he/she makes an investment decision in any one period.

3) Player A's individual return from units invested in market 2 depends on what percentage of the total tokens invested in market 2 was made by you.

4) By pressing -CALCULATE- during the experiment, player A will be able to have the computer calculate the investment return for MARKET 2 for individual and group decisions levels chosen by him/her. Try this now by pressing the -CALCULATE- key on your keyboard.

Up until now, if you have any questions, please do not hesitate to ask now.

DECISION SHEET (DESIGN I):

Let's take a practice trial to let you get a feel of what it means to actually invest in the endowment. Given that you have 30 units to invest, let's assume you decide to invest 12 units of your endowment in market 1 and your remaining 18 units in market 2. In this particular example we will also assume that other members of the group invested a total of 102 units as a group in market 2. This makes total units invested in market 2 = 120. Further, this means that you invested 15% of the group investment in Market 2.

MARKET 1:
You invested 12 units.

This gives you a return of 12 units of product 1 valued at $ 0.01 per unit.
Total Cash Return = $ 0.12

MARKET 2:
You invested 18 units.
The total group investment was 120 units.

This gives the group a return of –1,800 units of product 2, valued at $ 0.01 per unit.
Total GROUP Cash Return = $-18.00.
Your Cash Return = 15% of the total = $-2.70.

Total cash return for this round = $12.5 + $0.12 + $-2.70 = $9.92.

During the experiment you will be able to call up a summary of important details regarding the return from investments made in the alternative markets.

CALCULATOR:

Before player A makes an investment decision during the experiment, they will have the choice of using this option. By inserting an example level of group investment and individual investment chosen by them, they can have the computer compute the yield for Market 2 for the example they chose.

Choose an individual investment in Market 2: 10
Choose an example for group investment: 100

You will get:
Units of commodity 2 produced = -833
Group return = $-8.33
Individual return = $ -0.83

It is important you fully understand the opportunities for investment. If you have any questions, please raise your hand.

Player B's decision varies depending on experimental designs. Let's take a look at the design II first, followed by the design III.

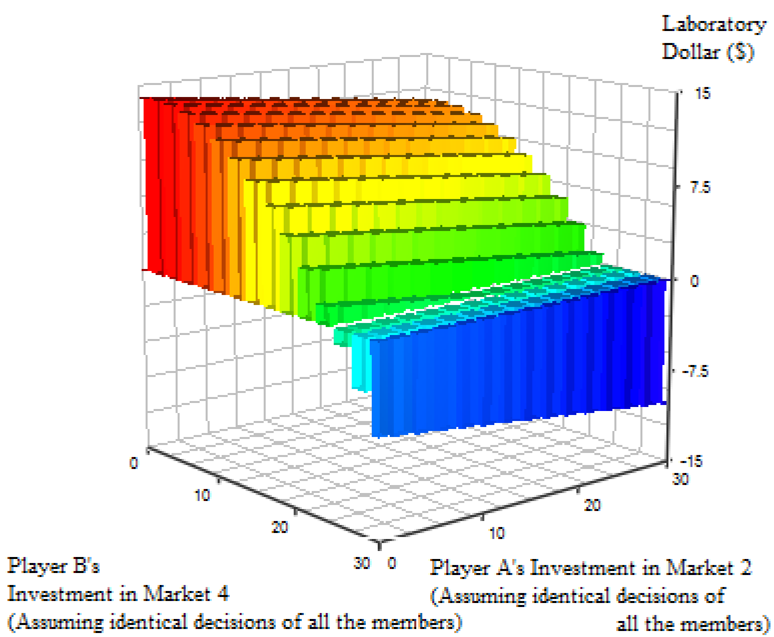
Design II (Instructions for Player B)

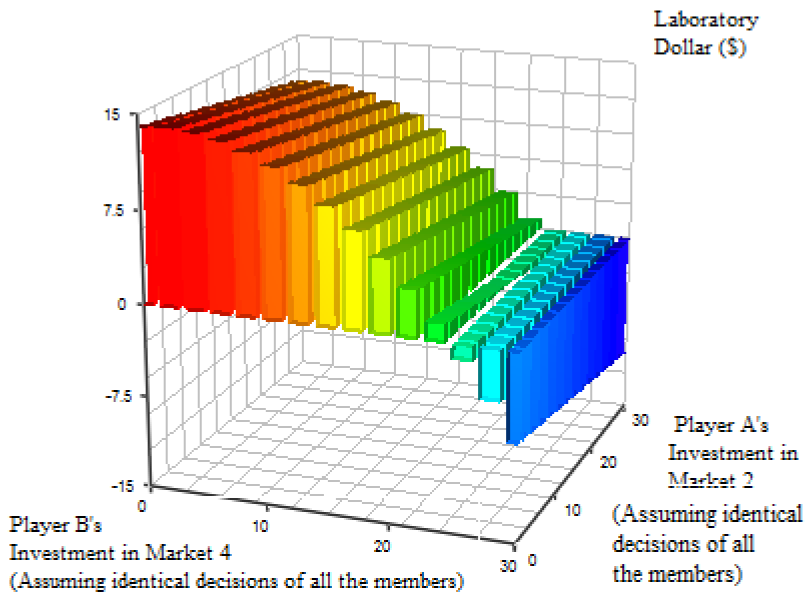
Player B will make the same decision as Player A. Player B's total earnings comprise return from market 3 and return from market 4. Player B's return on investment in market 3 is the same as market 1. Each unit invested in market 3 yields player B a return of one unit of commodity 3. Each unit of commodity 3 has a value of \$ 0.01. The return on investment in Market 4 is similar to Market 2, but not exactly the same. Units invested in Market 4 yield units of commodity 4. Each unit of commodity 4 has a value of \$ 0.01. The units of commodity 4 player B receives for investment in Market 4 is dependent upon how many units other members of the group invest in market 4 and player A's group investment in market 2.

Let us define x as the total number of units invested in market 4 by all members in group B and y as the total investment in market 2 by player A. We can calculate the number of units of commodity 4 produced as:

units of commodity 4 = $ax-bx^2+c-dy$
where: $a=10.5$ $b=1/3$ $c=6976/7$ $d=10$

The following two graphs show the range the above function can take with different viewing angles. Notice two different shapes of the function on x and y axes.





Total Units Invested in Market 2 by Player A

Total Units Invested in Market 4 by Player B	20	40	60	80	100	120	140	160	180	200	220
20	873	673	473	273	73	-127	-327	-527	-727	-927	-1,127
40	683	483	283	83	-117	-317	-517	-717	-917	-1,117	-1,317
60	227	27	-173	-373	-573	-773	-973	-1,173	-1,373	-1,573	-1,773
80	-497	-697	-897	-1,097	-1,297	-1,497	-1,697	-1,897	-2,097	-2,297	-2,497
100	-1,487	-1,687	-1,887	-2,087	-2,287	-2,487	-2,687	-2,887	-3,087	-3,287	-3,487
120	-2,743	-2,943	-3,143	-3,343	-3,543	-3,743	-3,943	-4,143	-4,343	-4,543	-4,743
140	-4,267	-4,467	-4,667	-4,867	-5,067	-5,267	-5,467	-5,667	-5,867	-6,067	-6,267
160	-6,057	-6,257	-6,457	-6,657	-6,857	-7,057	-7,257	-7,457	-7,657	-7,857	-8,057
180	-8,113	-8,313	-8,513	-8,713	-8,913	-9,113	-9,313	-9,513	-9,713	-9,913	-10,113
200	-10,437	-10,637	-10,837	-11,037	-11,237	-11,437	-11,637	-11,837	-12,037	-12,237	-12,437
220	-13,027	-13,227	-13,427	-13,627	-13,827	-14,027	-14,227	-14,427	-14,627	-14,827	-15,027

The table shown above presents units of commodity 4 produced depending on total investment made by player A and player B.

Examples:
1) if total units invested in Market 4 by Player B = 20 and total units invested in Market 2 by Player A = 20, then total units of commodity 4 = 873.
2) if total units invested in Market 4 by Player B = 140 and total units invested in Market 2 by Player A = 100, then total units of commodity 4 = -5,067.

Let's assume and fix total units invested in Market 2 by Player A = 60 and look at the table presented for market 2 in order to gain an insight how group investment of player B affects group return. This is shown in the previous table as column with a double border.

UNITS PRODUCED AND CASH RETURN FROM INVESTMENTS IN MARKET 4

Units Invested by Group	Units of Commodity 4 Produced	Total Group Return	Average Return per Unit	Additional Return per Unit Invested
15	479	4.79	0.32	-0.02
30	412	4.12	0.14	-0.12
60	-173	-1.73	-0.03	-0.32
90	-1,358	-13.58	-0.15	-0.52
120	-3,143	-31.43	-0.26	-0.72
150	-5,528	-55.28	-0.37	-0.92
180	-8,513	-85.13	-0.47	-1.12
210	-12,098	-120.98	-0.58	-1.32

commodity 4 value per unit = $ 0.01

The table shown above displays information on investments in market 4 at various levels of total group investment, fixing total units invested in Market 2 by Player A = 60. A similar table will be available during the experiment. Let's talk about the meaning of the information given in the table.

The first column "Units Invested by the Group" gives example levels of total investment by the group in Market 4. These are examples to give you a sense of the payoff from Market 4 at various investment levels. Actual return from Market 4 will depend on exactly how many units your group invests in Market 4.

The second column labeled "Units of Commodity 4 Produced" gives the level of units of commodity 2 produced for each level of group investment. For example, if 120 units were invested, there would be –3,143 units of commodity 4 produced.

The third column labeled "Total Group Return" displays the actual payoff to the entire group for a given level of group investment. For example, if the group invested 90 units, the total laboratory dollar payoff to the group from investing in Market 4 would be $-13.58.

The fourth column, labeled "Average Return per Unit," displays the laboratory dollar value at any level of investment, but on a per unit (average) basis. Thus, if the group invests 90 units, the average return per unit in Market 4 is $-0.15.

The final column, labeled "Additional Return per Unit Invested'", displays information on the extra value that is earned from additional units invested. Thus, when the level of group investment is at 90 units, the value of investing additional units into Market 4 is approximately $-0.52 per unit.

Up until now, if you have any questions, please do not hesitate to ask now.

IN SUMMARY:
1) The return you receive from units invested in market 4 depends on how many units you invest, how many units other group members invest in market 4, and how many units player A invests in market 2 in total.

2) You will not know how many units other group members have invested in market 4 when you make an investment decision in any one period. But you will know the total number of units player A invested in market 2.

3) Your individual return from units invested in market 4 depends on what percentage of the total units invested in market 4 was made by you after fixing the total number of units player A invested in market 2.

4) By pressing -CALCULATE- during the experiment, you will be able to have the computer calculate the investment return for MARKET 4 for individual and group decisions levels chosen by you. Try this now by pressing the -CALCULATE- key on your keyboard.

Up until now, if you have any questions, please do not hesitate to ask now.

DECISION SHEET (DESIGN II):

Let's take a practice trial to let you get a feel of what it means to actually invest your endowment. We will invite player A as well.

Let's assume each player A decides to invest 20 units of your endowment in market 1 and your remaining 10 units in market 2. In this particular example we assume that every member of the group invests 10 units in market 2, which makes total units invested in market 2 = 80. Further, this means that you invested 12.5% of the group investment in Market 2.

MARKET 1:
You invested 20 units.

This gives you a return of 20 units of product 1 valued at $ 0.01 per unit.
Total Cash Return = $ 0.20

MARKET 2:
You invested 10 units.
The total group investment was 80 units.

This gives the group a return of –133 units of product 2, valued at $ 0.01 per unit.
Total GROUP Cash Return = $-1.33.
Your Cash Return = 12.5% of the total = $-0.17.

Total cash return for this round = $12.5 + $0.20 + $-0.17 = $12.53.

Let's assume player B decides to invest 12 units of your endowment in market 3 and your remaining 18 units in market 4. In this particular example we will also assume that other members of the group invested a total of 102 units in the group. This makes total units invested in market 4 = 120. Further, this means that you invested 15% of the group investment in Market 4.

MARKET 3:
You invested 12 units.

This gives you a return of 12 units of product 3 valued at $ 0.01 per unit.
Total Cash Return = $ 0.12

MARKET 4:
You invested 18 units.
The total group investment was 120 units.
The total group investment in Market 2 by Player A was 80 units.

This gives the group a return of –3,343 units of product 4, valued at $ 0.01 per unit.
Total GROUP Cash Return = $-33.43
Your Cash Return = 15% of the total = $-5.01.

During the experiment you will be able to call up a summary of important details regarding the return from investments made in the alternative markets.

CALCULATOR:

Before you make an investment decision during the experiment, you will have the choice of using this option. By inserting an example level of group investment in market 2 by player A, an example level of group investment in market 4 by player B and individual investment chosen by you, you can have the computer compute the yield for Market 4 for the example you chose.

Choose an example level of group investment in market 2 by player A: 80
Choose an individual investment in Market 4: 10
Choose an example for group investment in market 4 by player B: 100

You will get:
Units of commodity 4 produced = -2,087
Group return = $ -20.87
Individual return = $ -2.09

It is important you fully understand the opportunities for investment. If you have any questions, please raise your hand.

Design III (Instructions for Player B)

In this design, Player B will make different decisions from player A. As before, player B's total earnings comprise return from market 3 and return from market 4, but player B will not make an investment decision. Your investment will be fixed at the average level of investment from the design II and only player A's decisions can vary. Player B's returns on investments in market 3 and market 4 are the same as design II. Each unit of commodity 3 and 4 has a value of \$ 0.01. The units of commodity 4 player B receive for investment in Market 4 is dependent upon the average units player B himself/herself and other members of the group invested in market 4 in the design II and player A's group investment in market 2 in the current experiments.

Let us define x as the average number of units invested in market 4 by all members in group B in the design II and y as the total investment in market 2 by player A in the current experiment. We can calculate the number of units of commodity 4 produced as:

units of commodity 4 = $ax-bx^2+c-dy$
where: $a=10.5$ $b=1/3$ $c= 6976/7$ $d=10$

The following table shows how many units of commodity 4 are produced according to the group investment made by both Player A and Player B.

Average Total Units Invested in Market 4 by Player B in Design II	Total Units Invested in Market 2 by Player A										
	20	40	60	80	100	120	140	160	180	200	220
20	873	673	473	273	73	-127	-327	-527	-727	-927	-1,127
40	683	483	283	83	-117	-317	-517	-717	-917	-1,117	-1,317
60	227	27	-173	-373	-573	-773	-973	-1,173	-1,373	-1,573	-1,773
80	-497	-697	-897	-1,097	-1,297	-1,497	-1,697	-1,897	-2,097	-2,297	-2,497
100	-1,487	-1,687	-1,887	-2,087	-2,287	-2,487	-2,687	-2,887	-3,087	-3,287	-3,487
120	-2,743	-2,943	-3,143	-3,343	-3,543	-3,743	-3,943	-4,143	-4,343	-4,543	-4,743
140	-4,267	-4,467	-4,667	-4,867	-5,067	-5,267	-5,467	-5,667	-5,867	-6,067	-6,267
160	-6,057	-6,257	-6,457	-6,657	-6,857	-7,057	-7,257	-7,457	-7,657	-7,857	-8,057
180	-8,113	-8,313	-8,513	-8,713	-8,913	-9,113	-9,313	-9,513	-9,713	-9,913	-10,113
200	-10,437	-10,637	-10,837	-11,037	-11,237	-11,437	-11,637	-11,837	-12,037	-12,237	-12,437
220	-13,027	-13,227	-13,427	-13,627	-13,827	-14,027	-14,227	-14,427	-14,627	-14,827	-15,027

Focus on the rows. Let's assume and fix total units invested in Market 4 by Player B = 40 and look at a similar table to that presented earlier to see how the group return for player B changes depending on the group investment chosen by player A.

UNITS PRODUCED AND CASH RETURN FROM INVESTMENTS IN MARKET 4

Units Invested by Group	Units of Commodity 4 Produced	Total Group Return	Average Return per Unit	Additional Return per Unit Invested
30	583	5.83	0.15	-0.09
60	283	2.83	0.07	-0.09
90	-17	-0.17	0.00	-0.09
120	-317	-3.17	-0.08	-0.09
150	-617	-6.17	-0.15	-0.09
180	-917	-9.17	-0.23	-0.09
210	-1,217	-12.17	-0.30	-0.09

commodity 4 value per unit = $ 0.01

The table shown above displays information on investments in market 4 at various levels of total group investment, fixing total units invested in Market 4 by Player B = 40. A similar table will be available during the experiment.

Up until now, if you have any questions, please feel free to ask now.

Player B will be provided with either a publicity option or a communication option. Player B's decision in this design is whether or not to exert these options.

PUBLICITY:
With this option, player B can send an anonymous message to all of player A. Player A will receive your message at the end of each round, but will not know who sent the message. The message will be uniform as follows:

"This message is to inform you that (*) % of players B is dissatisfied with your group investment in Market 2. They would like to ask all of you to reduce the amount of units invested in Market 2. Please make your decision that takes this notice into account."

Depending on how many of players B exercise the right, the percentage will be decided every round.

COMMUNICATION:
Player B can discuss the problem they face with a group of players A. Player B will be given 1 minute to hold such a discussion. Player B may discuss anything they wish during their 1-minute discussion period, with the following restrictions: (1) you are not allowed to discuss side payments (2) you are not allowed to make physical threats (3) you are not allowed to see the private information on anyone's monitor.

It is important you fully understand the optional actions available to you. If you have any questions, please raise your hand.

DECISION SHEET (DESIGN II):

Let's take a practice trial to let you get a feel of how this design works.

Let's assume each player B invested 20 units of endowment in market 3 and their remaining 10 units in market 4 on average in the previous design. This yields the average total units of 80 invested in market 4 by player B. Let's assume each player A decides to invest 20 units of their endowment in market 1 and their remaining 10 units in market 2. We assume that every member of the group A invests 10 units in market 2, which makes total units invested in market 2 = 80.

MARKET 1:
Player A invested 20 units.

This gives you a return of 20 units of product 1 valued at \$ 0.01 per unit.
Total Cash Return = \$ 0.20

MARKET 2:
Player A invested 10 units.
The total group investment was 80 units.

This gives the group a return of –133 units of product 2, valued at \$ 0.01 per unit.
Total GROUP Cash Return = \$-1.33.
Your Cash Return = 12.5% of the total = \$-0.16.

MARKET 3:
Player B's investment is given as 20 units.

This gives you a return of 20 units of product 3 valued at \$ 0.01 per unit.
Total Cash Return = \$ 0.20

MARKET 4:
Player A's investment is given as 10 units.
The total group investment is given as 80 units.
The total group investment in Market 2 by Player A was 80 units.

This gives the group a return of –1,097 units of product 4, valued at \$ 0.01 per unit.
Total GROUP Cash Return = \$-10.97.
Your Cash Return = 12.5% of the total = \$-1.37

During the experiments both players will be able to call up a summary of important details regarding the return from investments made in the alternative markets.

This ends the instructions. If you have any questions, please raise you hand.