Decision Making in a Dynamic Common Pool Resource Experiment

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Abstract

I present a dynamic common pool resource experiment where subjects have to make individual withdrawals in 20 rounds of decision-making. The subjects have a group account to withdraw from, that grows round by round depending on how much was left in the account in the previous round. I determine if subjects allow the resource to last through all the rounds. Also I examine what the differences are between the good and bad groups. I observed that some groups have the ability to make the resource last and also the good and bad groups have significant differences in their behaviors. I have found that there are differences in the frequency, persistence, and intensity of the different kinds of behavior that they exhibit.

Executive Summary

Common Pool Resources (CPRs) have been studied for decades with many experiments being run to better understand the behavior and management of CPRs. When CPRs were first being studied there was a lot of theory developed by people such as Garret Hardin (1968) who brought up the Tragedy of the Commons. The Tragedy of Commons is that people are self-interested which makes them take as much of the resource as they can, which leads to the resource being destroyed. Then people started to run experiments many of which have tried to determine if subjects could make a resource last through rounds of decision making. They have done this by having a group account that subjects withdraw from in each round, but most experiments so far are static. This means that there is no growth rate in the account's stock after each round or, in other terms, there is no evolution of the stock over time. This does not emulate a real life situation because a CPR such as a stock of fish reproduce over time and the stock grows through time. In 2015, Erik Kimbrough and Alexander Vostroknutov came out with a paper in which they ran a dynamic CPR experiment where they had a specific growth rate in between rounds of decision making. This is more realistic, but there growth rate had a certain threshold that if the account dropped below a certain level the resource would not grow for the next round. This is not representative of real life because even if there is a small amount of the resource left there should some growth for the next round.

The dynamic CPR game presented in this project uses a growth rate that was modelled after logistic growth where there is only growth if the account has something left in it. In the lab experiment, I ran 8 sessions with 2 groups in each session. This yielded a considerable amount of data to examine:

1. How well do the subjects self-govern?
2. Do some groups do better than others?
3. What are the differences between the good groups and bad groups?

From the data we were able to determine that some subjects are able to self-govern well and others could not. Once we realized this, we separated the groups into good and bad groups based on their total profit at the end of the game to determine the differences between the good and bad groups. To understand the differences between the groups we looked at the withdrawals of the subjects and determined whether they are responsible, irresponsible, or constructive. I was able to find out that there are significant differences between the responsible and irresponsible withdrawals of the good and bad groups. If everyone in a group made the same withdrawal decisions then with 32 LD in the account, 4 would be a responsible withdrawal because in the next round the stock would be back up at 32 LD. An irresponsible withdrawal would be 5 because if everyone took out 5 the account would drop to 12 LD and only grow to 27 LD for the next round. Now say there is 24 LD in the account and everyone withdrew 2 LD; that would be constructive because that would leave 16 LD in the account which would then grow by 16 and the next round will have 32 LD in the account. I then wanted to see whether the differences between groups was due to three different reasons:

1. How often are the groups responsible, irresponsible, or constructive?

2. Are the groups persistent with their responsible, irresponsible, and constructive withdrawals?
3. How intense are there irresponsible withdrawals?

To answer these questions I had to look at how often the good and bad groups used the different types of behavior. Also I had to determine the proportion of irresponsible withdrawals for good and bad groups to see how persistent they were with their behavior. Finally I looked at how intense their behavior was. I explain how I determine the intensity in the results chapter. I found that there is a significant difference between the frequency of responsible and irresponsible withdrawals of good and bad groups. The good groups are more frequently responsible than bad groups, and bad groups are more frequently irresponsible than good groups. Also we found that the bad groups are more persistently irresponsible than good groups. In addition, we found that the irresponsible withdrawals for the bad groups are more intense than the irresponsible withdrawals of the bad groups. Based on my findings, I make a couple recommendations:

1. Put a limit on the amount that people can take out from a CPR.
2. Educate people on the dangers of depleting CPRs.

These recommendations come from understanding that while some people are able to be responsible and preserve the resource through the rounds, other people are too irresponsible and kill the resource right away. This leads to me to believe there needs to be a limit on how much people can take out so that everyone is responsible. I recommend educating people on CPRs so that they understand the dangers of taking too much, since it will be very hard to enforce the limits that are placed on CPRs.

Table of Contents

Table of Figures

Table of Tables

1.0 Introduction

Common Pool Resources are nonexcludable and rival in consumption which means that anyone has access to the resource, but if someone takes some of the resource there is less of that resource for someone else to take. A good example of a CPR is a pond with a stock of fish. Anyone can come to the pond and take fish, but if someone tales some fish that fish is no longer available for someone else to take. This is how the CPR dilemma was created. Since anyone can come and take from the resource and there is nothing to stop them from taking as much as they want, resources start to dwindle and eventually the resource will be completely depleted.

Many people have attempted to run experiments to come up with a solution to the problem. Elinor Ostrom (1992) ran a static experiment where she concluded that individuals may be able to arrive at joint strategies to manage these resources more efficiently. She believes that individuals can do this if they have sufficient information to understand the allocation problem they are facing, and individuals also need a place where they can go to discuss joint strategies and perhaps implement monitoring and sanctioning. Since it was a static experiment, it does not fully represent a real life CPR situation. Therefore her conclusions did not help create policy that could fix the overuse of CPRs.

In my version of a dynamic CPR game, I conduct lab experiments representative of a real life CPR situation. My experiment allows for no communication between subjects and has a logistical growth rate that represents how a fish stock might grow in real life. I ran 8 sessions with 8 people in each session giving a total of 64 subjects. In each session the groups were split into groups of 4 and had to make withdrawal decisions in 20 rounds of decision making. They had a group account with 32 LD from which they could withdraw between 0 and 10 LD in each round. If they withdraw too much then there resource will become depleted before the last round and they will not achieve a maximum payoff. The subjects have a monetary incentive to make the resource last through the rounds so they can keep withdrawing more LD later converted into real money (1 LD=0.25 USD).

Past literature on CPRs attempt to solve the Tragedy of the Commons, but so far there have been few dynamic experiments. This is not good because the only way to really come up with a good solution is to model a real life CPR and if there is no growth rate in between rounds or time periods, then it does not model a real life CPR situation. The policy actions that have been suggested so far most likely will not work because of how different each CPR is. Each CPR has a different ecosystem that is hard to be modelled in a lab experiment, and one policy action cannot fix every situation because they are all different. I set out to answer 3 questions with my experiment:

1. How well do the subjects self-govern?
2. Do some groups do better than others?
3. What are the differences between the good groups and bad groups?

My data shows that some groups were able to make the resource last through the rounds while other groups did not do as well. Through regression analysis, I was able to determine that some groups were able to make the resource last until the last round, but some groups could not.

I was able to identify why those groups were not able to do as well through some statistical techniques such as regression analysis. I found that the bad groups were less frequent with their responsible withdrawals and much more frequent with their irresponsible withdrawals than the good groups. Also I was able to find that the irresponsible withdrawals of the bad groups were more intense than the good groups which lead to them killing the resource fairly early in the game.

My results show that subjects are not able to self-govern themselves. Some subjects are very frequent with their irresponsible withdrawals, others are persistently irresponsible, and a few people tend to make extremely irresponsible withdrawals. This leads me to suggest that policy action needs to be taken to limit the amount of a resource someone can take out one time and also educate the general population on the importance of preserving CPRs. A possible future project could involve adding a one-shot communication within the groups from my experiment. This could allow for the subjects to come up with joint strategies to preserve the resource, but also could educate the subjects and how to play the game.

2.0 Background-

The proper management of Common Pool Resources (CPRs) is something that many economists have tried to figure out for a long time. CPRs are resources that are similar to public goods, except that CPRs also face problems of overuse because they are rival in consumption. A common example of a CPR is a fishery. There are many fishermen trying to catch fish. If a fisherman catches a fish, then obviously another fisherman cannot catch that same fish. Each fisherman is trying to catch as many fish as they can so they can receive more benefits, but while every fisherman is trying to catch as many fish as they can, it takes fish away from the stock that was in the fishery and therefore takes fish away from other fishermen. The CPR dilemma is how to manage the resource to make sure that people do not overuse and deplete it. In the remainder of this chapter, I will be investigating past research on CPRs. There has been a lot of research on the subject and many different conclusions have come from the theoretical and experimental research. I will start by looking at the theoretical work and explain the CPR Dilemma in more detail, and then I will look at how the experiments have changed from when Economists first started looking at CPRs up until the present day. This will allow me to understand where the research is at this point and how I can add to it with my experiment. Also I want to take the knowledge from past experiments and compare them to my experiment.

2.1 An Overview of CPRs

Paul Krugman (2006) defines four types of goods: private, public, common resources, and artificially scarce goods. Private goods are excludable, meaning the suppliers of the good can prevent people who do not pay for consuming it, and they are rival in consumption, meaning the same unit of the good cannot be consumed by more than one person at the same time. Public goods are nonexcludable and nonrival in consumption, common resources are nonexcludable and rival in consumption, and artificially scarce goods are excludable but nonrival in consumption. Therefore common resources are open to everyone, but if someone takes some of the resource, then no one else can take what that person had already taken. This leads to the concept of externalities.

Externalities are both positive and negative where the positive externalities are the external benefits and negative externalities are the external costs to society. The negative externalities of CPRs are the negative effects that come from someone withdrawing from the resource. For example, if a fishermen catches a certain number of fish there is a negative externality on other fishermen because there are less fish to catch. There are a few ways to make CPR users internalize the costs they impose on others. First there could be a tax on the resource or some sort of regulation that limits how much of a resource can be withdrawn per person. Secondly, a system of tradable licenses for the right to use the common resource can be created. Lastly, the common resource could be made excludable and assign property rights to some individuals. Therefore the dilemma involved with CPRs is how to limit the effects of negative externalities on society and what action should be taken to limit the use of a resource to keep it from being depleted.

Garrett Hardin (1968) summarizes the Tragedy of the Commons by arguing that Adam Smith's "invisible hand" contributed to a dominant tendency to assume that decisions reached individually will, in fact, be the best decisions for society. Therefore Hardin argues that when thinking about common resources, people believe that what is good for them will be good for society so they will keep taking from the resource until their benefit from an additional unit of the resource is less than the cost. When in fact people are really trying to benefit themselves over society. Hardin then brings up an example where a herdsman asks himself "What is the utility to me of adding one more animal to my herd?" (Hardin, 1968, page 1244). When the herdsmen asks that question he sees that by adding another he reaps the benefits of all the proceeds from the sale of the additional animal and his negative component is only a fraction of what he would receive. So adding another animal would be good for him and he would just continuously add more animals until they have nowhere to graze anymore and they die off. So basically, each man is locked into a system that compels him to increase his herd without limit in a world that is limited. This example is a very good way to describe the Tragedy of the commons in a real life situation.

Hardin also suggests that morality plays a key part in peoples decisions meaning that people with good morals would understand that they cannot withdraw too much of the resource so that others can also withdraw from the resource and it will not become depleted. This morality principle is important when I analyze my data because I will need to differentiate between participants that are moral and will withdraw the correct amount to keep the resource from being depleted and participants that are not moral and withdraw whatever amount they want regardless of their groupmates. Hardin's biggest argument is that with the population growth we will have to concede to the tragedy of the commons. This means that with more people there has to be more regulation on the commons to provide for everyone. Since Hardin's paper, more educators have attempted to solve the problem involved with CPRs.

2.2 Potential Problems with CPRs

There are a couple of early papers that attempt solving the problem of CPRs through theory rather than experimentation. Scott Gordon (1954) mainly focuses on the fishing industry for his research into common pool resources. He uses many theories from different people, but before his time there were not many economic views of the subject. All of the papers regarding the fishing industries problem of overfishing took a biological view toward the problem. Since they took the biological view, they looked more into the environmental factors that lead to the depletion of fish including their predators and food sources which is not what Gordon wants to research. He instead researches how users of a resource change their actions due to policy changes. To do this, he did research into when Europe introduced limits on catching fish. When this happened people began to notice an increase in growth of the fish population. Therefore it is possible that the outside effect of fishermen could be having a bigger effect on the fish population than people had originally thought. Gordon argues that these limitations are a good thing and can help with overfishing, but there are also problems with these limitations because it made people more competitive and people would start spending more money on fishing gear that would allow them to get to the fish before their competitors. Also when people start spending more money on their gear then they need to catch more fish to compensate for the larger cost.

Gordon also argues that with some policy changes the fish population did not increase because of the limitations, but did so coincidentally. He then discusses by W. F. Thompson (1954), which shows that with an agreement between Canada and the US, the Pacific halibut fishery introduced a fixed-catch limit which ended up showing a significant rise in the fish population. When in actuality a careful study of the statistics indicates that the estimated recovery of halibut stocks could not have been due principally to the control measures, for the average catch was, in fact, greater during the years of fish population growth. This paper is the first to suggest that government intervention in CPRs is not necessarily needed to keep them from being depleted because past government intervention was not the reason for the increased resource stock. This means that there is another factor that is influencing user's actions, and that factor should be the basis for future research.

Adding on to Gordon's theory, Roy Gardner et al. (1990) went further into depth to find out individual incentives in CPRs and find that certain factor that Gordon noticed was there. They set out to see how various types of institutional arrangements and individual incentives used in relation to CPRs will lead to improved collective action problems. They end up using past research which presumes that when individuals use common resources jointly, each individual is driven by logic to take more of the resource than is optimal for all users. They classify this condition as a CPR dilemma. Then the authors lay out 4 assumptions that are required for a CPR dilemma. These four assumptions are:

1. if one person withdraws a resource unit, that unit is now not available to everyone else
2. there are multiple people withdrawing units of the same resource
3. the strategies that the individuals come up with depending on the physical system, technology, rules, market conditions, and attributes of the individual will lead to a suboptimal outcome from the individual's perspective
4. there is at least one strategy that is more efficient than all other decisions where the benefits exceed total cost

The first assumption is more commonly known as rivalry in consumption. This is an obvious assumption, but very important in our experiment because it factors into the decision making process of how much each group member chooses to withdraw each round. When the subjects in the experiment understand this assumption it makes them more likely to withdraw smaller amounts than they want each round to allow other group members to withdraw amounts small enough to make the resource last. So basically as long as the withdrawal rate does not exceed the natural replacement rate, the resource will not be exhausted. The second assumption also factors into the individuals' decision making process similar to assumption 1. Assumption three is basically, their decision to withdraw less to allow others to withdraw and to allow the resource to be sustainable is less than optimal for the individuals themselves. This does not mean that it is less optimal for the group of people using the resource, just the individuals themselves. Without assumption four there is no reason for people to try and come up with a strategy that helps everyone which leads to people only focusing on their own benefits and creates the problem of the commons.

Gardner et al. (1990) argue that theorists are split up into two groups when it comes to solving CPR problems. The first group believes that government action needs to take place to regulate CPRs, and the second group believes that private property rights need to be imposed which leads to the division of the commons into small chunks of private property and by doing this individuals are incentivized to produce optimal outcomes. This means that past theorists believe that one solution can be used for all CPR situations, but Gardner et al. believe that thinking of all CPR situations as CPR dilemmas causes several errors. First is that by thinking of CPR situations as CPR dilemmas there is a presumption that whenever multiple individuals take units from the resource suboptimal outcomes will occur, which is not always the case. Sometimes the quantity demanded is not high enough for individuals to pursue strategies that are suboptimal. Meaning that the resource does not have a high enough demand for people to withdraw too much of the resource because they will not receive any more benefits from an additional unit of the resource.

Another error that comes from thinking of CPR situations as CPR dilemmas is that in addition to CPR situations being CPR dilemmas there are also some situations where there is a non-problematic CPR or a resolved CPR. An example of a non-problematic CPR is where the CPR users have come up with a strategy by themselves that will lead to the resource not being depleted. With that in mind, when reforms are made the non-problematic CPRs and resolved CPRs are included in the sweep of policy recommendations. So these policy changes could unravel an already Resolved CPR situation as the solution imposed from the outside does not account for the prior solution evolved by the individuals themselves.

There are also sub problems within each individual CPR situation. One of which is that not all situations are structured like the Prisoner’s dilemma, where two rational individuals might not cooperate, even if it appears that it is in their best interest to do so. Some are structured like an Assurance game where no one person’s contribution is sufficient to gain a collective benefit, but both person’s contribution will produce joint benefit. Meaning that both layers would prefer to contribute to the provision of a collective benefit if and only if the other player also contributes. I think this is very important to take into account in our experiment because it could be possible that if one person in the group withdraws a large amount that is not beneficial to everyone, then the other group members will then change their decisions and start withdrawing more based on the fact that not everyone is contributing to the common good.

James Walker et al. (1990) then turn to look at how each CPR situation is different for the consumer. They believe that problems that individuals face when dealing with CPR situations can be put into two groups: appropriation and provision problems. With appropriation problems, the production relationship between yield and level of inputs is assumed to be given and the problem to be solved is how to allocate the yield in an economic and equitable way. To solve this problem they believe that focusing on the allocation of the yield of a resource in terms of the quantity of resource units to be appropriated or the dual problem of determining the efficient level and mix of input resources necessary for obtaining that yield, the timing and location of appropriation, and the appropriation technologies adopted is the way to go. When thinking about appropriation problems I think it is important to look at technological externalities. These occur when the presence of some users or their technologies increase production costs for other users. This is very important in CPR situations because when production costs increase for certain individuals they start withdrawing more of the resource to make up for those costs creating a problem. Another important aspect of appropriation problems is rent dissipation. Rent is basically the benefit that the individual receives from the resource. So the problem with rent dissipation is that the rent gets smaller whenever the marginal returns are not equal to the marginal costs. This means that the strategic behavior of the individual makes it so they will invest inputs as long as the average return exceeds the marginal cost.

Provision problems, on the other hand, are related to creating a resource, maintaining or improving the production capabilities of the resource, or avoiding the destruction of resource systems themselves. So basically they focus on the behavioral incentives for individuals to contribute resources for the provision or maintenance of a CPR, supply side provision or alter appropriation activities within an existing system in such a manner as to change the withdrawal patterns from the CPR so as to maximize multiple period returns or even possibly avoid the extinction of a biological resource, demand side provision. This is a very important part of CPR situations because the main problem policy makers are trying to fix is making sure the resource lasts. The authors believe that even though individuals face combinations of appropriation and provision problems, it is better to analyze them as two separate problems to gain a clear understanding about what is involved in reducing the severity of each problem. So, basically Walker et al. believe that all CPR situations are different and there cannot be one solution to all the problems.

2.3 Early Experiments Attempting to Solve CPR Problem

Walker et al. (1990) investigated the strength of the theoretical models that have been out forth by other authors which predict that users of common pool resources will appropriate units at a rate at which the marginal returns are greater than marginal costs. They put forth the idea that given that individuals appropriate resource units in a setting where marginal changes in that appropriation have external effects on the costs of the appropriation and increases in the level of appropriation by individual users lowers the marginal physical product to investment by all users, the external nature of this effect and the lack of well- defined property leads to individuals ignore the marginal effects and focus on average returns from investment. Meaning that the individuals are focusing on the wrong thing which leads to a dissipation of the rent or benefit they would receive. This all means that they are trying to see why people end up withdrawing too much of the resource.

The experiment consisted of groups of people that are given a certain amount of tokens at the beginning of the game. They are then allowed to invest their tokens into one of two markets. The first market was an investment opportunity where each token yielded a fixed rate of output and in which each unit of output yielded a fixed rate of return. The second market is a market which yielded a rate of output per token dependent upon the total number of tokens invested by the entire group. The subjects were then informed that they would receive a level of output from market 2 that was equal to the percentage of total group tokens they invested and that each unit of output from market 2 yielded a fixed rate of return. So basically market 2 is the CPR where the total output is what everyone puts into the market rather than in market 1 where there is a fixed rate of output per token. So basically if someone invests too much to market 2 then there will be a negative externality on everyone else because as a group they will end up investing over the socially optimum level.

The important part of this experiment is that the subjects have experience with a similar decision game which increases the likelihood of them understanding the problem and the repercussions of alternative levels of individual and group investment decisions. This is important when looking at this experiment because it does not simulate what would happen in real life. When common people are faced with a decision regarding CPRs they do not have this understanding of what their decisions will do to others therefore they will do what they think is best for them. The authors then use three predictions that will help in describing the results of the experiment. First is that entry is limited to eight players with a fixed level of input of tokens. Second, the marginal opportunity cost of investing in the CPR is constant because the return per token from market 1 is constant. Lastly, the value of output units produced from investments in market 2 is constant. With these predictions the authors are using an environment that is closely related to a limited-access CPR in their experiment.

They ran this experiment with some groups having a 10 token endowment for each subject and some groups of having a 25 token endowment per subject. They saw a glaring disparity between the rents accrued for the different endowments. They found that the average level of rents accrued in the 10 token design equaled 37.2% whereas in the 25 token design the average level was 3.16% (Walker et al. 1990). They also found a pattern in when people reduce their investment in market 2. They noticed a pulsing pattern where rent is reduced, at which time the investors tend to reduce their investments in market 2 which lead to an increase in the rent. Even with this pattern there was not symmetry across the experiments in the amplitude of the timing of the rent peaks. This means that there was not one specific time where all the groups changed their investments when they saw the rent decreasing. It is important to note that they also did not see any clear signs that the experiments were stabilizing as the rounds went on. This is important because this means that it is tough for people to find the right level of investment by themselves, therefore their needs to be a policy to help people make the right decisions. Also the data shows that when the capital available for appropriation increases, the severity of the problem increases.

Then in a paper without Elinor Ostrom, Walker and Gardner (1992) combat the problem of the destruction of a CPR. They believe that there is a range of safe yield in each CPR and there is a natural regeneration process present that implies a certain range of exploitation in which the probability of destruction is zero. Also, if that specific safe yield is surpassed, the resource faces probabilistic destruction. This means that people have a dilemma between whether they want to jeopardize the life of the resource or earn benefits from the resource. The authors created five experiments with the design 1 that the safe zone is a single point and 7 experiments with design 2, the safe zone being an interval. Design 2 led to higher efficiency and the resource lasted longer. This is kind of misleading because in only two of the experiments with design 2 did groups follow an investment pattern generally in the vicinity of the good subgame-perfect equilibrium and in the remaining five experiments with design 2 groups followed an investment pattern dispersed around the bad subgame-perfect equilibrium.

Walker and Gardner conclude that this data does not bode well for CPR survival in environments where no institutions exist to foster cooperative behavior. Even though there is a focal point Nash equilibrium which yields near-optimal rent, the subjects tend to not be able to stabilize at the equilibrium point. Also, even though the renewable resource in the experiment is well defined, in real life the one period payoffs fluctuate wildly. For example, in a fishery the fish reproduce at different times and at different levels so it is very tough to simulate those fluctuations. This fact leads Walker and Gardner to conclude that it is going to be tough to come up with the best policy to improve low efficiencies because it will take time to learn natural settings and by that time the resource might already be destroyed. They also conclude that the behavior in their laboratory CPR environment adds additional evidence to field data regarding the need for well-formulated and –tested institutional changes designed to balance appropriation with natural regeneration.

Elinor Ostrom then joins back up with Walker, and Gardner to further extend their work with the probabilistic destruction of a resource to find out the best way to govern CPRs (Ostrom et al, 1992). After Walker and Gardner's experiments in their last paper, (Walker and Gardner, 1992), they believed that the resource would surely become extinct if an institution was not put in place governing a certain CPR. They took this a step further with the help of Ostrom, and came up with a couple of different experiments to test whether people could come up with their own agreements that would allow everyone to benefit from the resource or if they need an institution to come up with rules and enforce them.

They also added another aspect into their experiments in terms of communication between group members. In these experiments they had some experiments have a one-time communication between members in which they are allowed to come up with a strategy that will help everyone, and some experiments with repeating communication after each round. I believe that adding this variable of communication was what lead them to change their views of what the best policy is for CPRs. In addition to the communication, they also added an element of punishment where participants can fine other group members. This is a monetary fine that can be levied, but the person who levies the fine incurs a fee as well. This leads to interesting results when this punishment mechanism is introduced. They first believed that there needed to be institutions in place to govern CPRs, but after these experiments they realize that given the chance to communicate with each other the people and punish others using the CPR, people have the ability to devise a strategy that will help everyone and the resource itself.

The experiments lead Ostrom et al. to come up with two major implications. The first is that policymakers responsible for the governance and management of small-scale, CPRs should not presume that the individuals involved are caught in an inexorable tragedy from which there is no escape. Individuals may be able to arrive at joint strategies to manage these resources more efficiently. The authors believe that individuals can do this if they have sufficient information to understand the allocation problem they are facing, and individuals also need a place where they can go to discuss joint strategies and perhaps implement monitoring and sanctioning. The second implication was that in finitely repeated social dilemma experiments, a wide variety of treatments that do not change the theoretically predicted subgame consistent equilibrium outcomes do change subjects' behavior. This means that the changes they made in each experiment, whether it be how much communication the group had or the endowment they started with, changes the individuals behavior.

I agree with their conclusions because in their data, the difference between the net yield when the subjects could communicate and when they could not was especially large. They said that in the low endowment CPR environment, average net yield increased from 35% (when no communication was allowed) to 99% (when communication was allowed on a repeated basis). Also, in the high-endowment CPR environment, average net yield increased from 21% (when no communication was allowed) to 55% (when communication was allowed only once) to 73% (when communication was allowed on a repeated basis). This is a glaring statistic, and is very important when talking about policy action toward CPR environments. This data shows that people have the ability to come up with a viable solution to their problem with communication instead of having someone else tell them what they can and cannot do. I think there is a way to incorporate behavioral economics into this, because you could say that people are more willing to go along with rules that they came up with themselves rather than rules that were imposed on them by someone else. This tendency is often referred to as the "democracy premium" (Dal Bo et al. 2010). So allowing the communication between subjects, the authors of this paper are allowing the subjects to make their own rules which they are more likely to follow because they came up with the rules by themselves rather than some unknown institution.

Also they have conclusions involving what happens when the punishment mechanism is introduced. With an imposed sanctioning institution and no communication they found subjects are willing to pay a fee to place a fine on another subject far more than was predicted, and in the high-endowment environment, average net yield increases from 21% with no sanctioning to 37% with sanctioning. When the costs of fees and fines are subtracted from average net yield, however, net yield drops to 9%. This shows that subjects overuse the sanctioning mechanism, and sanctioning without communication reduces net yield. Then when they examined only the high-endowment environment, they found that with an imposed sanctioning mechanism and a single opportunity to communicate, subjects achieve an average net yield of 85%, and when the costs of fees and fines are subtracted, average net yield is still 67. These represent substantial gains over the baseline, where the net yield averaged 21%. Also with the right to choose a sanctioning mechanism and a single opportunity to communicate, subjects who adopt a sanctioning mechanism achieve an average net yield of 93%. When the costs of fees and fines are subtracted, average net yield is still 90%. In addition, the defection rate from agreements is only 4%. Also, subjects who do not adopt a sanctioning mechanism achieve an average net yield of only 56%. In addition, the defection rate from agreements is 42%. This reinforces the idea that when people are allowed to choose the institution that has control over how much people can withdraw from a resource, they are more likely to follow the rules.

2.4 Dynamic CPR Experiments

The dynamic experiments involved with CPRs can be separated into two sections. The first section includes papers that did experiments with a logistic growth pattern. The second section includes papers with experiments that have different growth functions that lead to some interesting conclusions.

2.4.1 Experiments with Logistic Growth

The first paper that modeled dynamic growth was written by Andrew Muller and Finlay Whillans (2008). They were also the first to introduce a logistic growth rate after each round. They ran 4 laboratory experiments: a static model with no communication, a static model with communication, a dynamic model with no communication, and a dynamic model with communication. This allowed them to model what happens in real life because in real life there is the possibility of communication and it is a dynamic environment. The results from the static environment were very comparable to earlier studies. In the absence of communication, appropriation effort converged rapidly to the Nash prediction and cycled around it. Introducing non-binding communication clearly reduced average effort and increased efficiency, with clear differences in the ability of groups to achieve coordination. Behavior in the dynamic environment was, on first impression, very different from that in the static environment. In almost all cases subjects responded to changing stock levels by varying their fishing effort over a much wider range. Introducing non-binding communication allowed subjects to hold back on current effort to build up stocks, and most groups exploited this opportunity.

The effort to start using a dynamic environment with logistic growth patterns in experiments did not end with Muller and Whillans (2008). Another paper with a dynamic environment and a logistical growth rate is the one done by Charles Noussair et al. (2015). In their experiment, instead of using a laboratory setting, they use a field setting where there are actual fishermen fishing from a pond. In each session, sixteen fishermen were assigned to groups of four, with fixed membership. Fishing took place in four periods of 1 hour each. Subjects could catch as many fish as they liked, as long as total catch did not exceed the stock available to their group. Regeneration was mimicked by throwing in extra fish at the end of each period depending on the number of fish remaining (Noussair et al. 2014). They ended up concluding that there was no evidence of cooperation. Their results were consistent with standard economic theory that assumes selfish preferences and non-cooperative behavior. The difference between their results and results from past laboratory experiments show that contextualization is important when testing a renewable resource model. To achieve good social outcomes in the field setting they used, voluntary cooperation is not enough, and specific institutions that promote cooperation, such as punishment technologies or voting processes, may be required.

2.4.2 Dynamic Experiments with Other Growth Patterns

Anabela Botelho et al. (2013) integrated the two main features involved in CPR dilemmas, evolution over time and management under uncertainty. While each of these two features has been analyzed separately in the experimental literature, no attempt has been made to integrate them into a single experimental setup. In this paper, they seek to examine whether the conclusions derived from models of dynamic games with no environmental uncertainty are still valid when uncertainty is introduced, and whether the conclusions from static models of environmental uncertainty in the basic CPR game transfer to time-dependent settings. This experiment is different from other dynamic experiments because there is not a growth rate that affects the stock after each round, but there is a different stock every time between two different uncertainty levels.

Through this experiment they seek to answer two questions that cannot be answered without integrating both of the features discussed above. These questions are, what are the strategies that appropriators adopt when both environmental uncertainties and temporal considerations are present, and are the strategies that they adopt sensitive to different levels of environmental uncertainty? In their experiment design there were two different uncertainty levels. With high uncertainty the participants were told that each round will begin with a resource size between 150 and 850 and they can withdraw up to 850 tokens. If the tokens taken by the group in total was more than the resource size then no one will get a payoff and the game will be over. This leads to people choosing small amounts of tokens so they do not go over the resource size and can continue the game. With low uncertainty the resource size is anywhere from 270 to 730 and participants can withdraw the same as in high uncertainty. This group has the ability to take more tokens than the high uncertainty group because they have a smaller range of values from the resource size and have a better idea of what the size will be for each round.

They end up concluding that the CPR users quickly use up the resource and end the game. This means that with uncertainty over the size of the resource CPR users are not able to come with decision strategies that leads to the resource becoming sustainable. This experiment is similar to our experiment because we focus on decision making over time, but I think our experiment relates more to real life because in their experiment they have a random resource size for each period instead of having a starting resource size that grows after each round depending on what is left after each round. The only uncertainty aspect in our experiment is that each participant does not know who is in their group whereas in their experiment there is uncertainty with the resource size. I think to enhance their experiment, the first round of the game should have an uncertain resource size, but then after that round if the resource is not extinguished it should grow with a certain growth rate each round. I think this simulates a more realistic CPR dilemma and could offer new conclusions to add to their paper.

Caroline Schill et al. (2015) run a laboratory experiment to answer the question: How does the risk of an undesirable ecosystem regime shift influence user group exploitation strategies and collective action? Their experiment is very similar to ours, they took a bunch of students and put them in groups of four and they had a stock of 50, but the participants could take up to 50 out at one time. Also they had a similar regeneration pattern as us, but once the stock level gets below 20, the regeneration drops off which makes it almost impossible to come back from. This means that if a participant takes too much and the stock gets below 20, the regeneration rate drops off and the group will exhaust the resource in the next round or two. They also did not disclose the number of rounds to the participants so now they do not know when the experiment will be over and will not be inclined to exhaust the resource at the end of all the rounds. Also the participants were allowed to communicate orally to their group mates to disclose their individual harvesting rates, where we do not disclose who is in what group so they cannot communicate.

They end up concluding that that whether or not people face such a latent shift with certainty or different risk levels does not make them more or less likely to exploit the resource beyond its critical potential threshold. Even though this was their conclusion I wonder if the results would have been different without communication. I believe that if there was no communication then people would be more likely to exploit the resource because they do not have the social pressure of limiting their exploitation.

In 2015, Erik Kimbrough and Alexander Vostroknutov furthered the work done by Schill et al. (2015). In this paper, they also use a dynamic environment and a similar growth rate in between rounds of the laboratory experiment. Kimbrough and Vostroknutov's growth rate is liner with a certain threshold. Whenever subjects take tokens from the group account, its size diminishes by the sum of the tokens taken. Before the next period, the group account replenishes: if there are X tokens remaining, then next period the group account will contain $X+ \beta(360-X)$ tokens (β is the treatment-dependent growth rate). However, if the number of tokens remaining falls below 30, then the group account would not replenish. This is similar to other growth rates in the past, but it models a real life CPR environment better than past growth rates.

In their paper they bring up a really good point about CPR users and how they are broken up into two groups, rule-breakers and rule-followers. Where groups of rule-breakers may deplete a resource that would otherwise be preserved and groups of rule-followers may preserve a resource that would otherwise be depleted. They also hint at the importance of assortative matching and the exclusion of rule-breakers to the successful management of CPRs. This is very important when I end up analyzing the data from our experiment because I need to be able to distinguish between groups that follow the rules and preserve the resource until the end of the game, and groups that break the rules and deplete the resource prior to the last round.

Their experiment is pretty similar to ours, but they uses a couple different resource growth rates which leads to some important conclusions. Also, unlike our experiment they run a rule following game where they test if people will follow the rules even though it will cost them more money. They simulate a character walking across the screen with 5 red lights, if the player waits at the red light instead of just walking through then they incur a fee. This will show if people will follow the rule of the red light or try to maximize their money by not incurring the fees involved with waiting at the red light. After this test, they used the results to sort participants into groups for the CPR experiment. This allows them to see whether the presence of rule-followers can lead to the preservation of a low resource growth rate CPR.

They end up siding with Gardner et al. (1990) in the conclusion that there is a very strong relationship between ecological and social factors in preserving CPRs. They also concluded that when the resource growth rate is high, the presence of rule-followers is still needed to preserve the resource, but not everyone in the group had to follow the rules. Then when the resource growth rate was low, only groups composed completely of strong rule-followers could preserve the resource. This is very important when studying all the CPRs in the world because each CPR situation has a variety of people benefitting from the resource and it is hard to distinguish between rule-followers and rule-breakers.

Lluis Bru et al (2003) run an experiment to determine what type of policy actions need to be made to preserve common pool resources. The authors do this by first running an experiment where participants are grouped together with a partner. Each partner is making sequential decisions on whether to withdraw a large share of the stock (H) or a smaller share of the stock (L). Partner one first chooses to take either H or L, then partner two is informed about partner one's decision and the stock grows by a constant growth rate. Then partner two decides whether to take out H or L. This decision making goes on for 6 rounds, which gives each partner the chance to withdraw 3 times. The equilibrium for this experiment is LLLLHH. Therefore both partners want to start by taking out the lower amount (L) in the first two rounds of their decision making, and then they should end their decision making by choosing the larger amount (H). The authors also run a few different treatments where the H value gets even higher than in the other treatments which makes it more tempting for the participants to choose H over L. In their results they found that the most used strategy was LLLLHH, but they did find that in the treatments where H was higher than usual, participants tend to give in to temptation and withdraw H more often. At the end of the experiment, the authors decided to make policy suggestions based on their results.

They believed that in the context of natural resource management, their results suggest that the closer the capacity (H-value) is to the quota (L-value), the higher is the tendency not to surpass the quota. This is important because policy makers can both impose quotas and target capacity. Therefore, the authors suggested that policy changes need to be made directed toward reducing capacity because when capacity is too large relative to the quota, the fleet tends not to comply with the quota. This experiment is different than ours in a couple different ways. First of all, they are using groups of 2 rather than 4 and each partner is making sequential decisions rather than all 4 group members making decisions in every round. Also the participants in this study got to choose between two decisions either a large share of the stock or a small share of the stock rather than choosing any number between 1 and 10 in our experiment. Their growth rate was also different than ours because of the way they have the participants withdraw. To figure out how much will be in the account for the next round they either use the equation $((1-H)*100)$or$((1-L)*100)$ and then they triple what comes out of that. This is also different than any other growth rates used because it is a constant growth rate rather than a dynamic one.

2.5 More Experiments related to CPRs

Marco Janssen (2010) attempts to expand upon Ostrom et al (1992) and Hardin (1968) by adding more variables to make his experiment more lifelike. He believes that experimental research has not addressed the problem of fit because of two limitations of current designs. The first is that the common resource representation used in experiments is often static, deterministic, and non-spatial. Even though he believes that, he understands that past experiments were instrumental for showing the possibility of self-governance for common-pool resources but are limited from an ecological perspective. The second limitation is that participants in experiments are typically only able to make a decision about how much to harvest from a common resource. That is why in Janssen's experiments participants can make decisions where, when, how, and how much to harvest in a real-time experimental environment.

Basically the experiment is that participants start off with two individual rounds where they can collect tokens on a grid, then the third round is collective in groups of four, where the grid is bigger and all participants can collect as tokens again. In this first group round there is no communication, then in the next round communication is introduced through text messages between groupmates. Here is another instance of where the communication factor is not used correctly. The communication variable should be used to make people stay in line and do not take too much of the resource through social pressures, but if the communication is over the phone, then people do not really have that social pressure because they are not confronted by someone face to face. There was also a punishment aspect to his experiments where someone could punish someone by spending a token to make someone lese give up two tokens as punishment. Not many people used the punishment method, and I think it is because people did not want to spend their own tokens to punish someone because that would take away from how much they benefit themselves. In the end Janssen concludes that when participants have the option to craft institutional arrangements on when, where, and how to appropriate a resource, they do so, and those arrangements fit the ecological dynamics of the resource.

Janssen et al. (2010) go over the same experiment as the one in Janssen (2010). They conclude that communication significantly increases the group's performance, but the performance is not sustained when punishment is used and communication is no longer possible. These findings stress how important communication is when dealing with CPRs. Also they bring up how back in 1968, Hardin concluded that overharvesting of a CPR was inevitable unless an external authority imposes rules on the users. They bring this up because they try to prove that communication between the users of a CPR can lead to a smart strategy that will not eliminate the resource.

Janssen (2013) sets up experiments to figure out how the information that resource users have influences their decisions. In this paper he adds on to what he previously did in his previous paper, Janssen (2010). Once he understood that communication between group members was important to the sustainability of a resource, he decided to take a look at how the information they have affects how well they communicate. He found that participants harvested more single tokens when they could not be seen by others which means that when information is limited and people cannot be monitored they tend to stray from their informal agreements they made with the group. Therefore he concludes that information is a key component to explain the level of cooperation between group members.

Janssen et al. (2013) allow participants to elect a regulation from a limited set of possible institutional arrangements to see if the elected rules will lead to better performance and how compliant the participants are. There is a major difference between the experiments they run in this paper and the experiments that Janssen has run in the past. They introduce a real world experiment including members of villages in Columbia and Thailand as participants in the experiment. This is very important in encapsulating the entire dilemma that comes with CPRs because it has all the variables that come with a real world situation. From these experiments they noticed that participants tended to break the rules that they put into place which he thinks can be explained by the distrust of externally proposed regulations. The most amount of rule breaking came from the villages and they believe that is because of the amount of trust the community members had in each other to not conform to the rules. So if one person believes everyone else will not follow the rules, that person will not follow the rules as well. This leads them to conclude that it is important to take the social context of the community of resource users. This is shows the importance of how regulations are implemented and how their effectiveness is the result of interactions between social norms and rule enforcement.

Fischer et al (2004) argue that since almost all naturally occurring CPRs are intergenerational common pools, it seems obvious that intergenerational dynamics constitute an important aspect of CPR exploitation and deserve more attention. In this paper they seek to address the question of whether the intergenerational perspective of the CPR appropriators can contribute to the sustainability of the resource use. They first use a basic common pool resource model in which there are groups of 3 and each person chooses a level of effort to be exerted in exploiting the common pool resource. The socially optimum equilibrium in the author's model is 9, therefore to reach the social optimum each player should choose an effort level of 3. Then they have an intergenerational common pool resource model where the level of effort from one generation effects the amount that the next generation can exert. If the players in a generation aim at providing the next generation with exactly the same income opportunities as they have themselves, it is necessary that they make exploitation effort choices that just compensate the natural growth of the resource. Such growth compensating behavior is focal, because the provision of equal opportunities is often viewed as a basic fairness norm. Also, if the resource grows slower than necessary to compensate the equilibrium exploitation, growth compensation requires that players choose exploitation efforts below the equilibrium level. But, if the resource grows faster than the equilibrium exploitation can offset, growth compensation requires that players choose exploitation efforts above equilibrium level.

The authors found that people had trouble predicting what level of exertion the other players would do in the same generation. This could mean that subjects actually intend to maximize their own monetary payoffs, but fail to do so, due to wrong expectations concerning the choices made by the other players. What the authors found was that subjects in all three treatments intend to sacrifice some of their payoff for the well-being of others. The authors also found clear and strong evidence that the presence of an intergenerational link affected subjects' expectations concerning the behavior of their peers. Although, while expecting their peers to face up to the intergenerational responsibility, subjects did not reduce their own exploitation levels in the presence of an intergenerational link. Since considerable restraint in resource extraction was expected, yet only moderate restraint was practiced, the resource stock diminished in a social climate of unjustified optimism. This means that there is a coordination problem between group members which could happen in our experiment because our subjects have to make decisions without knowing the decisions of their group members. Some good did come out of this study though because the authors learned that subjects genuinely care about each other which lead them to a lower extraction level than the equilibrium, and the subjects recognized the intergenerational responsibility. This means that people understand that we need to make sure that we do not exhaust common pool resources so that future generations can use them as well. What they found in this experiment is different than what we could find out from our experiment because at the end of 20 rounds, anything left in the account is lost. This means that the subjects in our experiment want to exhaust the resource in the last round to maximize their payoff because there is no future generation in our environment.

2.6 Summary

The main question that theorists are trying to answer through these experiments is whether people can come up with their own strategies to keep a CPR from becoming extinct without government intervention. When looking at all of this research it is easy to see the current state of literature regarding CPRs. So far it is important to note that most theorists believe that it is not possible to allow CPR users to come up with their own strategies to keep the resource from depleting. Theorists also realized that communication between CPR users can help users come up with good strategies, but in real life CPR environments CPR users have trouble communicating because they can withdraw from the resource at different times so they do not have any communication. My experiment can help add on to the knowledge that past experiments have brought to CPRs. Our growth rate is different than all of the past experiments I have looked at because our graph of the growth function clearly shows the experimental subjects how much they should take out each round in order to keep the resource form being depleted. This should allow subjects to come up with their own strategies that will benefit everyone in the group without communication. This allows me to correctly model a real life CPR environment and figure out if people are actually able to come up with their own strategy that will lead to a sustainable CPR situation without an institution in place to monitor it.

3.0 Methodology

In this section, I explain the design of my experiment and provides a basic analysis of the game. The design includes how I recruited participants, the lab setting of our experiment, and the procedure that the participants follow. The basic analysis includes an explanation of the growth model, the social optimum, and the subgame perfect Nash equilibrium. Based on the analysis of the game, I propose eight hypotheses of how the participants will play the game.

3.1 The Experiment

3.1.1 Participant Recruitment

All participants were undergraduate students recruited from introductory economics classes at WPI during the spring of 2017. Students were informed about the experiments during their lectures. If interested, students could join the mailing list to receive information about upcoming experiments. Once a date was set for an experiment, an email would be sent out to the mailing list with the experiment's time and place. This email would be sent out 2 days in advance of the session so that students would have enough time to register. In the email there were also simple instructions on how to register for the experiment.

Registrations were supported by the Regi 25 web application, which is maintained by the Computing and Communications Center of Worcester Polytechnic Institute. Regi 25 offer registrations for events from various departments around campus. To register, students would click on a link included in the email. After logging in using their WPI user name and password, the Regi 25 page would come up and students could register for the session offered. To learn more about Regi 25, please refer to its website: http://www.wpi.edu/webapps/regi/.

Each session included 8 participants. However, during registration, one or two extra students were usually invited in case of no-shows. If everyone that registered showed up, the extra couple of students would not be able to participate, but they were given a $10.00 show up fee and received extra credit for their introductory economics course. Those students that could not participate also had the option to register for future sessions.

3.1.2 Lab Setting

All sessions took place in the Department of Social Science and Policy Studies' Experimental Economics Lab located Salisbury Labs. During the experiment, subjects were seated at private computer workstations, and all interaction occurred over the computer network. The experiment was programmed and conducted with the experiment software z-Tree (Fischbacher, 2007). All procedures for the experiment were programmed into the software beforehand so that there would be minimal interaction between the experimenters and the subjects. During the experiment, subjects simply followed the instructions on their computer screens and entered their decisions using keyboards and mice. The experimenters were available for help if subjects had any questions during the experiment.

3.1.3 Setup

To setup for this experiment, I had to make 16 copies of the Informed Consent Forms, 8 Instructions, and 3 Receipt forms. I then put two copies of the Informed Consent Forms at each computer workstation so that each participant could sign one and give it back, and keep the other one. I then made sure that all the computers were turned on and functioning correctly so that there were no problems when the participants arrived.

Once all the participants were in place, I read the Informed Consent Forms aloud and answered any questions. Then, I asked the participants to sign the forms and I went around and collected them. I passed out the instructions for the experiment and explained how the game works to the participants. Once I finished I answered any questions they had and then started the experiment.

3.1.4 Procedure

The participants were randomly and anonymously matched with 3 other participants over the computer network. I used groups of 4 in this experiment because 4 is the most common group size in past literature.

Each member of the group had access to the common group account from which they could withdraw money in each of 20 rounds of decision-making. Using 20 rounds I was able to lessen the impact of irresponsible behavior once more. This way people would be willing to take less in a certain round to correct irresponsible behavior and still have plenty of rounds left to make up for taking less early. Another reason for using 20 rounds was to have a large sample of decision making and with more rounds people could have more time to figure the game out.

Each person in the group made their own individual decision on how much to withdraw from the shared account. At the beginning of round 1, the account had 32 lab dollars (LD) in it. The game started with 32 LD in it because this allowed each person to make a moderate withdrawal (4-5 LD) and for the stock to be in the range of optimal growth.

Each of the four participants in a group made a withdrawal between 0 and 10 LD in each round. (See Appendix B1 for the decision screen). Participants had no control over how much their groupmates withdrew. We only let the participants withdraw anywhere from 0 to 10 because it allows them to make large withdrawals, and also does not let the large withdrawals get out of hand. If we allowed participants to withdraw more than 10 then some people that are not taking the experiment seriously could potentially kill the experiment.

The account then became 32 LD less the sum of the withdrawals of each group member. The participants would then be informed of the total amount withdrawn from the account and the new account balance. The account would then grow before the start of the next round. The account would grow depending on how much was left in the account from the previous round. The participants were informed on how the account will grow by Figure 1, included in the instructions passed out before the experiment started. After the account grew, the participants would make withdrawals just as they did in round 1.

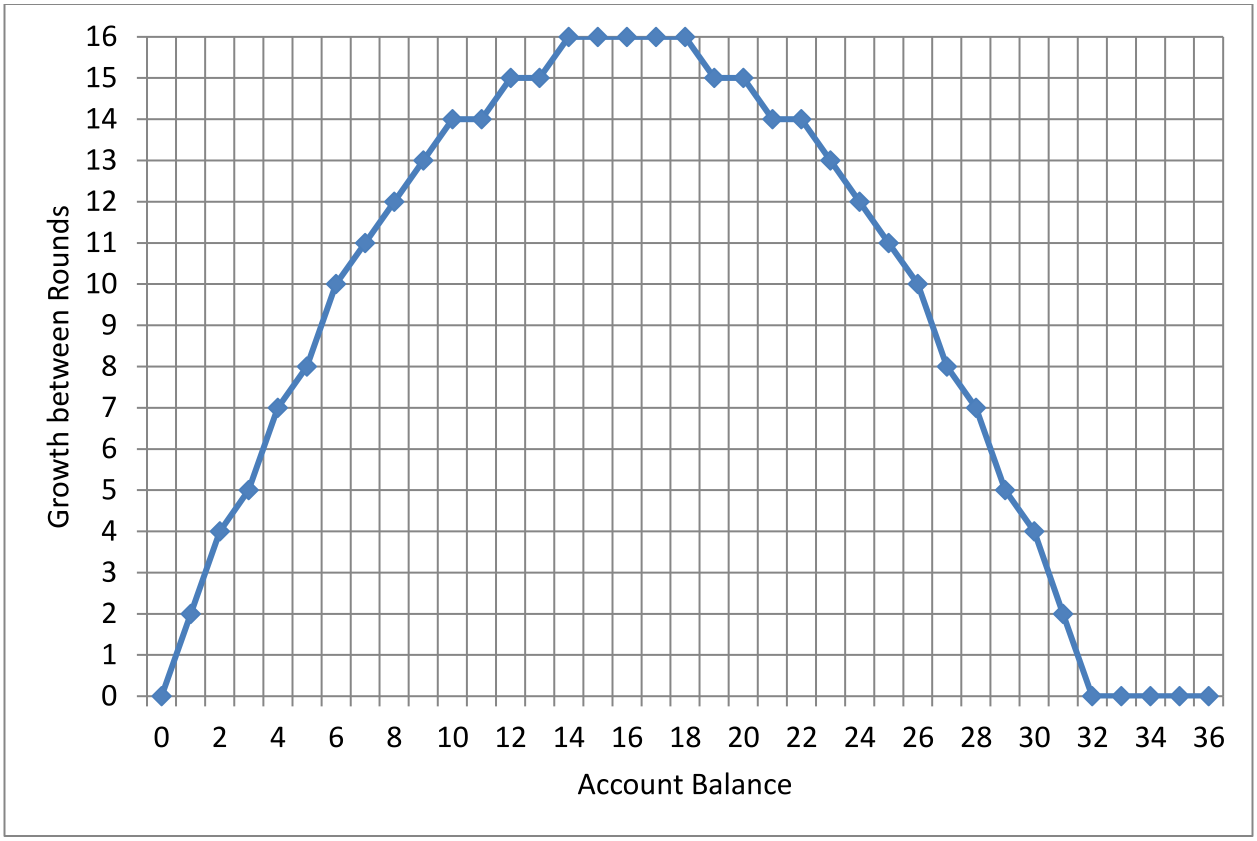

Figure 1: Account Growth between Rounds

We used this growth function because we wanted to simulate real life the best we could. With this growth function, if the account balance gets below 14 then the account will start growing less. Also we made it so if the account balance gets beyond 18 the growth rate will also slow down. A real life example of this could be fish in a pond. If the population of fish get too small then the rate at which they repopulate will be lower because there would be less breading, and if the population gets too large the rate of repopulation will be slow as well because the environment has a maximum carrying capacity. This means that the fish will reach a certain point where their population cannot grow anymore because there is not enough space in their environment to contain more fish.

This puts a big emphasis on the decisions of the participants because they need to make decisions to keep the account from going below 14 and above 18. If the withdrawals of all four participants does not bring the account below 18 and above 14, then they are not being efficient. If they take out less than 14 and the account stays above 18 then they are leaving money in the account that they can take out without effecting the new account balance. If they take out more than 18 and the account drops below 14 then they are taking out too much money that can affect how much money they can take out later.

This process continued for 20 rounds. If, before the end of round 20, the account had nothing left in it, the participants advanced through the remaining rounds by withdrawing 0. As long as the sum of all the withdrawals in the group was no larger than the amount in the account, everyone would receive their withdrawals. If the withdrawals exceeded the amount in the account, then the account was divided as follows:

i. Anyone who chose a withdrawal of a quarter or less of the amount in the account got his/her withdrawal. Such withdrawals were deducted from the amount in the account and those people were considered "paid."

ii. If and when the remaining number of people is 3, any of those 3 people who chose withdrawals of a third or less of the amount remaining in the account got his/her withdrawal. Such withdrawals were deducted from the amount remaining in the account and those individuals were considered "paid."

iii. If and when the remaining number of people is 2, either of those 2 people who chose withdrawals of a half or less of the amount now remaining in the account got his/her withdrawal. Such withdrawals were deducted from the amount now remaining in the account and those people were considered "paid."

iv. For any people remaining, the amount now remaining in the account was divided evenly.

After each round the participants were given feedback on how much they received from their withdrawal and how much was left in the account. (See Appendix B2 for a screenshot of the feedback). Then they received more feedback about how much the account grew. (See Appendix B3 for a screenshot). Once all the rounds were done, we asked the participants to provide some demographic and contact information. (See Appendix B4 for a screenshot). Then the amount that each participant withdrew over the 20 rounds would be converted into real money at a rate of 1 LD to 0.25 USD. Finally, they were paid in a private manner and the experiment was over.

3.2 Data

3.2.1 Data Description

Variable	Obs	Mean	Std. Dev.	Min	Max
Profit	1,280	3.1	2.05	0	10
TotalProfi	1,280	34.86	22.09	0	110.5
newstock	1,280	10.65	7.32	0	32
growth	1,280	10.84	5.73	0	16
stock	1,280	21.48	10.69	0	36
endstock	1,280	9.09	5.78	-3.55E-15	22
withdraw	1,280	3.16	2.1	0	10
SumW	1,280	12.66	6.49	0	29
received	1,280	3.1	2.05	0	10
SumR	1,280	12.39	6.55	0	28
money	1,280	8.71	5.52	0	27.625
stock_pc	1,280	5.37	2.67	0	9
endstock_	1,280	2.27	1.45	-8.88E-16	5.5
growth_p	1,280	2.71	1.43	0	4

Table 1: Summary Statistics of Data

The data set from the experiment includes information on all the individual withdrawals for the 8 sessions of the experiment. Each session include 2 groups with 4 subjects each. Table 1 includes the summary. The *profit* variable is the amount that the subjects received in each round, while the *totalprofit* variable is the sum of what the subjects received. The *newstock* is what the stock will be in the next round, while *stock* is how much they have in the account in the current round. The *endstock* is the stock at the end of each round after the subject's withdrawals, and *growth* is how much the account will grow into the next round. The *withdraw* variable is how much the subject decided to withdraw in each round, but they do not always receive the amount they decide to withdraw. *Sumw* is the sum of all the withdrawals for each subject, while *sumr* is the sum of the amount each subject received. *Money* is there total profit converted into real money. The last five variables I created to id the subjects and groups in a better way so I could test them.

3.2.2 Social Optimum

In this experiment, there is a strategy which leads to the maximum sum of benefits over group members. This is what we call the social optimum. The social optimum in this experiment is if everyone in the group withdraws 4 in each round, until the last round where everyone should take out as much as they can. This is the social optimum because when everyone in a group withdraws 4, the account will decrease to 16, which will then grow by 16 bringing the account back 32. Keeping the account at 32 allows for the maximum benefit to the group. The last round of the game is a little different because anything left in the account at the end of the game is lost, which means lost benefit. This means that everyone needs to double their withdrawal in the last round to completely use up the resource.

3.2.3 Subgame Perfect Nash Equilibrium

To find out what the subgame perfect Nash equilibrium of our game is, we have to use backward induction. To use backward induction we have to assume all subjects are rational and self-interested, knowing this is the final period of the game, they should play the dominant strategy in a single-shot game. This means that they would take out as much as they can. The rules of the game only allow them to take out a maximum of 10 from the account in each round. This means that in the last round the participants should all withdraw the maximum amount of 10. Anticipating that this will happen in round 20, we then take a look at round 19 and determine what participants would do in this round. Once again theory states that participants should use the dominant strategy and take out the maximum. This continues throughout all the rounds which shows that the subgame perfect Nash equilibrium is when participants withdraw 10 every round. This also means that the resource should be exhausted within the first round.

3.3 Methods of Analysis

3.3.1 How Well Do Subjects Self-Govern?

To answer this question I looked at the behavior of the subjects, if they are irresponsible most of the time they are not able to self-govern very well. My results show that some subjects are able to self-govern well and act responsibly for a good amount of the time, but there are some groups that are irresponsible more of the time and cannot self-govern themselves. This means I will be using the summary statistics of the behaviors for all the groups to see if the groups are more irresponsible or responsible.

3.3.2 Do Some Groups Do Better Than Others?

To answer this question, I first looked at the average profits of each group, allowing me to separate the groups into high-performing or “good” groups and low-performing or “bad” groups. This is shown in Table 2.

groupid	11						groupid	51					
Variable		Obs	Mean	Std. Dev.	Min	Max	Variable		Obs	Mean	Std. Dev.	Min	Max
TotalProfit		4	52	23.30951	24	81	TotalProfit		4	77	15.12173	65	99
groupid	12						groupid	52					
Variable		Obs	Mean	Std. Dev.	Min	Max	Variable		Obs	Mean	Std. Dev.	Min	Max
TotalProfit		4	71.25	9.569918	59	82	TotalProfit		4	80.25	7.804913	71	90
groupid	21						groupid	61					
Variable		Obs	Mean	Std. Dev.	Min	Max	Variable		Obs	Mean	Std. Dev.	Min	Max
TotalProfit		4	40.25	9.429563	29.5	51.5	TotalProfit		4	36	4.690416	31	40
groupid	22						groupid	62					
Variable		Obs	Mean	Std. Dev.	Min	Max	Variable		Obs	Mean	Std. Dev.	Min	Max
TotalProfit		4	78.25	22.07751	60.5	110.5	TotalProfit		4	11	5.944185	4	18
groupid	31						groupid	71					
Variable		Obs	Mean	Std. Dev.	Min	Max	Variable		Obs	Mean	Std. Dev.	Min	Max
TotalProfit		4	70.25	11.44188	59	86	TotalProfit		4	82.5	6.936217	73	87.66667
groupid	32						groupid	72					
Variable		Obs	Mean	Std. Dev.	Min	Max	Variable		Obs	Mean	Std. Dev.	Min	Max
TotalProfit		4	53.5	17.21434	38	78	TotalProfit		4	79	12.98717	66	97
groupid	41						groupid	81					
Variable		Obs	Mean	Std. Dev.	Min	Max	Variable		Obs	Mean	Std. Dev.	Min	Max
TotalProfit		4	45.25	17.65172	20	60	TotalProfit		4	72.25	11.70114	61	87
groupid	42						groupid	82					
Variable		Obs	Mean	Std. Dev.	Min	Max	Variable		Obs	Mean	Std. Dev.	Min	Max
TotalProfit		4	71.25	9.322911	59	79	TotalProfit		4	71.5	15.29161	50	85.5

Table 2: Average Total Profit by Group

I also graphically analyzed the difference between the best group and worst group by graphing their *endstock* by *period*. This is shown in Figure 2.

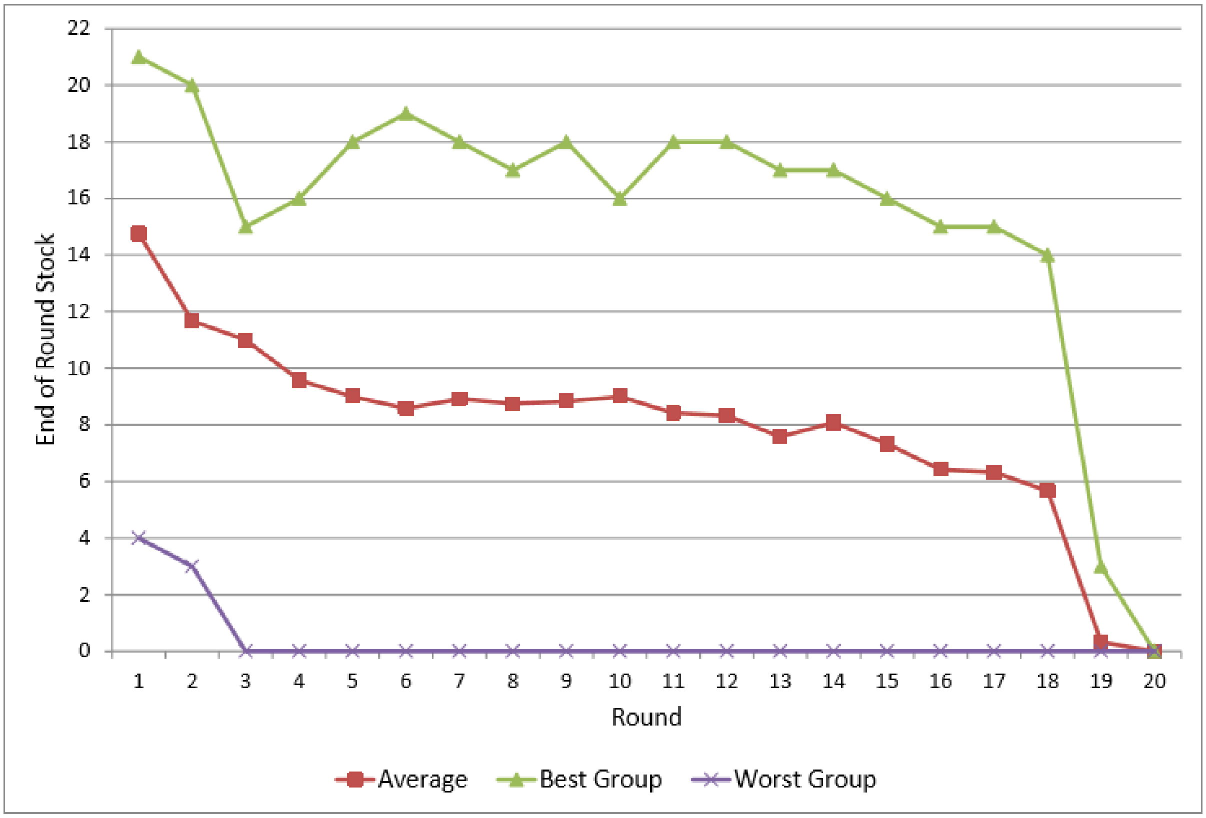

Figure 2: Best, Worst and Average groups End of Round Stock by Period

Note: Figure 2 includes sessions 1-6, does not include sessions 7 an 8.

Figure 2 shows that while the best group is able to keep the stock at a steady level throughout the game while the worst group killed the resource almost immediately. I also used regression analysis between the good and bad groups to see if there were any significant differences in the data. This allows me to see if the good groups are significantly more responsible than the bad groups or if the bad groups are significantly more irresponsible than the good groups.

3.3.3 What are the Differences between the Good and Bad Groups?

To answer this question I had to analyze the frequency, persistence, and intensity of the subject's behavior. Finding out the frequency of their behavior I can tell if the good groups are responsible more of the time or if the bad groups are irresponsible more of the time. Finding the persistence of the groups behavior will allow me to determine if the bad groups are more persistent with the irresponsible withdrawals, meaning they do not care they are being irresponsible and they just keep being irresponsible. Finding the intensity of the group's behavior will allow me to determine if the bad groups are more intense with their irresponsible withdrawals which would make it hard for those groups to recover.

3.4 Hypotheses

If we assume that everyone is self-interested, then everyone will try to receive the highest payoff by withdrawing as much as they can and hope that everyone else does not withdraw as much as they can as well. If everyone does this then the resource will be exhausted immediately.

Although from past experiments we see that participants have been able to not exhaust the resource in the first round. This means that the participants are thinking intuitively and lowering their first few withdrawals to make the resource last longer. All withdrawals can be categorized into three groups: responsible, irresponsible, and constructive withdrawals.

Where g is growth, s is the stock and x is the withdrawal.

- A withdrawal is responsible if $4x = g(s - 4x)$; or $s - 4x > 14$,
- A withdrawal is irresponsible if $4x > g(s - 4x)$; and $s - 4x < 14$.
- A withdrawal is constructive if $4x < g(s - 4x)$.

To better understand what this would look like is through a couple examples.

Ex1: If the account has 32 LD and a subject withdraws 5 LD, it is an irresponsible withdrawal because if everyone takes out 5 LD then 20 LD is withdrawn and the account would drop to 12 LD. Then it would only grow by 15 LD and the new account balance would be 27 LD.A responsible withdrawal in this instance would be 4 LD. Account would drop to 16 LD then grow back by 16 LD.

Ex2: If the account has 24 LD and a subject withdrew 2 LD, it is a constructive withdrawal because if everyone takes out 2 LD then the account would drop by 8 LD leaving 16 LD in the account. The next round the account would grow by 16 LD and the account would be up to 32 LD for the next round

From this we can construct our first hypothesis as:

H1: Players will make responsible and constructive withdrawals in the beginning rounds to learn how their groupmates are making decisions.

As the participants move forward through the rounds, they will have a better understanding of the game and how their groupmates are making decisions. This is deceiving because all participants are trying to do the same thing, which means when they think they can ramp up their withdrawals, everyone will do the same. This allows us to construct our second hypothesis:

H2: Players will start making irresponsible withdrawals after the first few rounds to increase their benefit.

Since they receive feedback after every round, they will know how much is left in the account after their withdrawals. If they do not exhaust the resource with their irresponsible withdrawals they will be able to recover from these withdrawals by changing their behavior. From this we can construct our third hypothesis:

H3: Players will change their behavior and start making more responsible withdrawals.

Once the participants reach the last few rounds, they should start increase their withdrawals once again. This should happen because everyone is self-interested and want to receive the most benefit. This leads participants to make extremely irresponsible withdrawals. From this we can construct our fourth hypothesis:

H4: Players will increase their withdrawals and exhaust the resource before the last round.

According to past literature by Botelho et al (2013), Ostrom et al (1992), and Ostrom et al (1990) participants are not able to stabilize their withdrawals at the equilibrium point and end up exhausting the resource before the last round of the game. This would mean that in our experiment, participants will have a tough time achieving the social optimum, but since our growth rate is simple enough for participants to comprehend, they should be able to come close to the social optimum. From this we can construct a hypothesis about how long the stock will last:

H5: The stock will last until the last few rounds, but will be exhausted before the last round of the game.

Even though responsible behavior by participants are associated with good groups, participants in bad groups can also show some responsible behavior. The responsible behavior will be more prevalent in good groups because they have a higher total profit which means they probably lasted longer in the game. From this we can construct a hypothesis regarding responsible behavior in good and bad groups:

H6: There is more responsible behavior within the good groups than in the bad groups.

Looking at the differences between groups, there should be more irresponsible behavior in the bad groups. The bad groups have a lower total profit which means they probably killed the resource early with irresponsible withdrawals. From this we can construct a hypothesis regarding the irresponsible behavior in good and bad groups:

H7: There is more irresponsible behavior within the bad groups than in the good groups.

Since there should be more irresponsible behavior in the bad groups they should have to use more constructive behavior to correct for their irresponsible behavior. From this we can construct the last hypothesis:

H8: There is more constructive behavior within the bad groups than in the good groups.

To test these hypotheses, I will be mostly analyzing the withdrawals of the participants. First, I will separate the groups into good and bad groups based on how long they made the resource last. Secondly, I will look at the withdrawals of each subject within each group to determine their behavior. I will then check to see if the withdrawals of good and bad groups match up to my hypotheses on how the behavior changes between groups.

4.0 Results-

4.1 Behavior through Rounds

To determine whether the groups start of being responsible and gradually become more irresponsible as the game goes on I created regressions of each of the three behaviors with the period to see if the behaviors are decreasing or increasing through the rounds.

	responsible withdrawals	responsible withdrawals
	by good groups	by bad groups
	b/se	b/se
Period	-0.007*	0.004
SE	0.000	0.000
stock	0.029***	0.005
SE	0.000	0.000
_cons	-0.616***	0.034
SE	0.12	0.08
r2_a	0.377	0.045
r2	0.386	0.061
N	632	532

Table 3: Regression of Responsible Withdrawals by Good and Bad Groups

From Table 3 it is evident that the good groups got less responsible over time which means the subjects started of responsible and slowly got less responsible over the rounds. The figure also shows that bad groups got more responsible over time, but it is not significant so we cannot rely on that to understand the behavior of the bad groups. Even though the positive coefficient could mean that the bad groups are becoming more responsible later in the rounds to make up for their irresponsible behavior in the beginning rounds. To take a better look at that I looked at the irresponsible withdrawals of the good and bad groups.

	irresponsible withdrawals	irresponsible withdrawals
	by good groups	by bad groups
	b/se	b/se
Period	0.019***	0.009
SE	0.000	0.000
stock	-0.001	0.017***
SE	0.000	0.000
_cons	0.317*	0.087
SE	0.15	0.11
r2_a	0.097	0.047
r2	0.109	0.063
N	632	532

Table 4: Regression of Irresponsible Withdrawals by Good and Bad Groups

From Table 4 it is evident that the good groups are significantly getting more irresponsible as the rounds go on which falls in line with what I found from Table 2. The important information from this regression is that the bad groups are not significantly getting more irresponsible as the round goes on, but as the stock goes up the bad groups are significantly more irresponsible. This means that when the stock was the highest, which it is in the first round, the bad groups are more irresponsible. This indicates that the bad groups are more irresponsible early in the game than the good groups which leads the bad groups to killing the resource early. To determine whether the bad groups were irresponsible early in the game I decided to look at the constructive withdrawals to see if the bad groups got less constructive as the round goes on meaning they had to be constructive early to make up for their early irresponsible withdrawals.

	constructive withdrawals	constructive withdrawals
	by good groups	by bad groups
	b/se	b/se
Period	-0.012***	-0.012**
SE	0.000	0.000
stock	-0.028***	-0.022***
SE	0.000	0.000
_cons	1.299***	0.879***
SE	0.14	0.11
r2_a	0.121	0.068
r2	0.133	0.084
N	632	532

Table 5: Regression of Constructive Withdrawals by Good and Bad Groups

In Table 5 it is evident that both good and bad groups get significantly less constructive as the rounds goes on, but the one that really matters is the bad groups. This is because I have already established that the good groups are responsible to start and get more irresponsible as the rounds go on. Since the bad groups are getting significantly less constructive as the round increases, but do not get significantly more responsible or irresponsible than it is evident that they were irresponsible to start the game which lead to them having to become constructive early in the game to make up for it. Then they might have been able to get less constructive once their stock grew larger. To take a deeper look into the differences between the groups I looked at the frequency, persistence and intensity of the group's responsible, irresponsible, and constructive behavior.

4.2 Differences in Behavior between Good and Bad Groups

To test the frequency of the behavior we took the summary statistics of the behaviors before round 20 and if the new stock is greater than 0 because everyone should be irresponsible in the last round and if the new stock is 0 then everyone's withdrawals would be responsible skewing the data. I was able to create a table with the frequencies of the behaviors for good and bad groups.

	RW	IRW	SCW
Good Groups	31.80%	34%	35%
Bad Groups	16.00%	46%	37.60%
	t = -6.1014	t= 4.2874	t = 1.0398
	df= 1074	df= 1074	df= 1074
	Pr(T < t) = 0.00	Pr(T > t) = 0.00	Pr(T > t) = 0.1493

Table 6: Frequencies of behavior by Good and Bad Groups

I also ran some t-tests to determine if the differences between groups were significant. The results are summarized in Table 6. For responsible behavior, the difference between the bad and good groups is significant. This means that the good groups are significantly more responsible than bad groups. For irresponsible behavior, the difference between the bad and good groups is significant, which means that the bad groups are significantly more irresponsible than good groups. There ended up being no significant difference in constructive behavior between groups. This lends evidence to hypotheses 6 and 7.

To test the persistence of behavior between groups I created Figures 3 and 4 that visually shows the proportion of irresponsible behavior for good groups and bad groups.

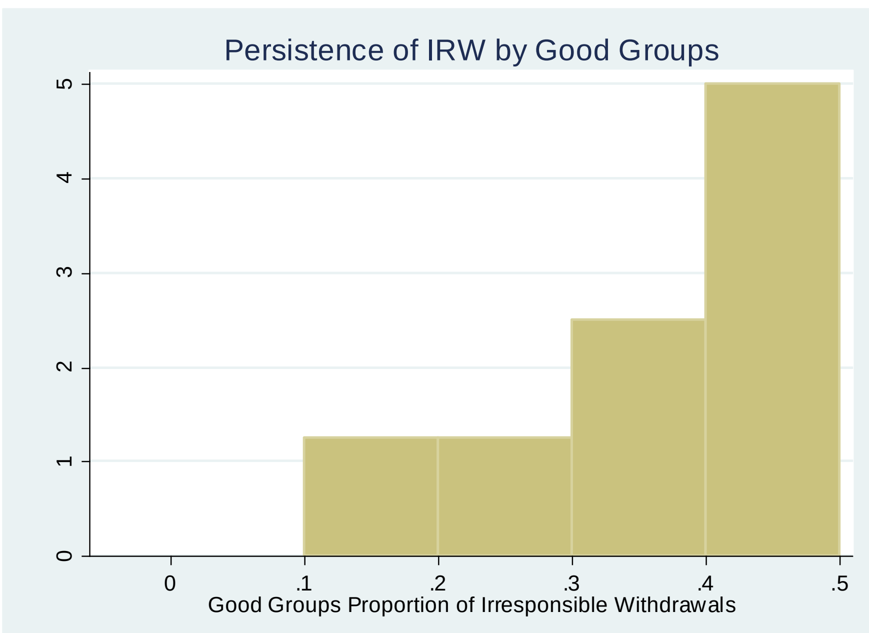

Figure 3: Persistence of IRW by Good Groups

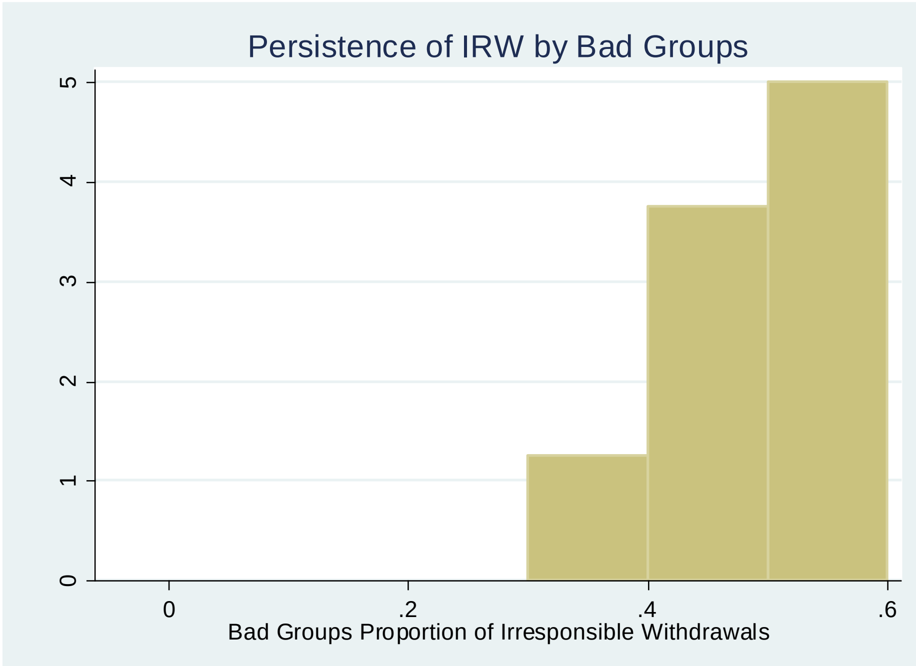

Figure 4: Persistence of IRW by Bad Groups

Figures 3 and 4 show that bad groups are persistently more irresponsible than good groups. This is because the proportion of irresponsible withdrawals are higher in the bad groups than in the good groups. This means that subjects in the bad groups continuously make irresponsible withdrawals, possibly because they do not understand the game.

To test the intensity of the withdrawals I had to examine each individual withdraw compared to what should be responsible in each situation. For example if the account balance is between 34 and 30, 4 is a responsible withdrawal, and if the account is between 20 and 30, withdrawing 3 is responsible. As the group account drops the responsible withdrawal in that situation drops as well. By doing this we can tell whether there are subjects that are being very irresponsible. I created a graph to visually see the intensity of people's withdrawals.

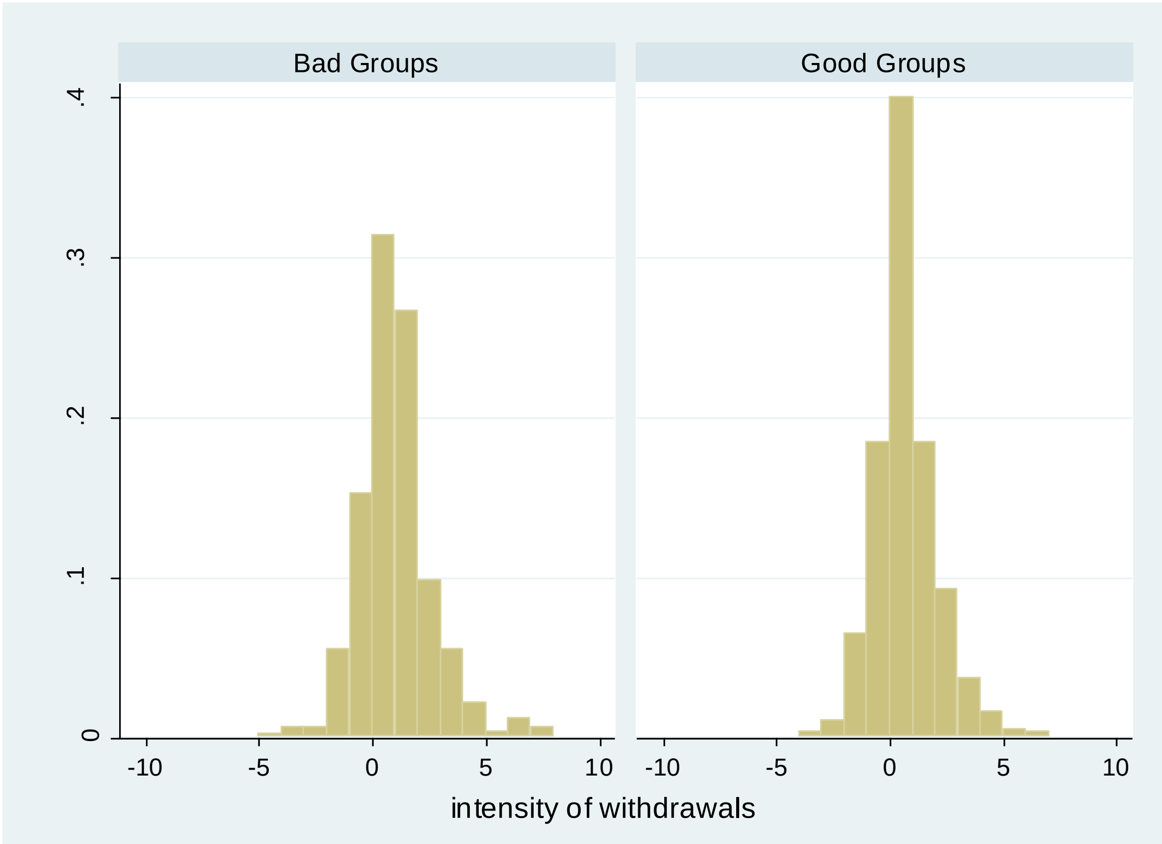

Figure 5: Intensity of behavior in Good and Bad Groups

From Figure 5 it is evident that some subjects in the bad groups are withdrawing large amounts and are more intense with their irresponsible withdrawals. We can tell that because the right tail of the bad groups graph is larger than that of the graph of the good groups. From the tables and graphs it is easy to see the differences between the groups, and can say that it has to do with the frequency, persistence, and intensity of the behaviors. Clearly some subjects can make the resource last, but other people end up taking too much.

4.3 Summary

From the regressions we were able to identify how the behaviors change through the rounds. The responsible and constructive behavior decreases through the rounds while irresponsible behavior increases. This goes along with my first two hypotheses. My third hypothesis was unable to be tested because it was difficult to test if the behavior trended more toward responsible behavior after a few irresponsible withdrawals. Through some more regressions I was able to show that there are fewer observations in the bad groups than in the good groups, which shows that the bad groups end up killing the resource before the end of the game. Also some of the good groups killed the resource before the end of the game which confirms hypothesis 4 because most of the groups killed the resource before round 20, but does not confirm hypothesis 5 because some groups killed the resource very early rather than in the last few rounds. Finally, with a table and some graphs, evidence was given to support hypothesis

6 and 7. There were significant differences between good and bad groups with the frequency of their responsible and irresponsible withdrawals, as well as visual evidence that there are differences in the persistence and intensity of irresponsible behavior between groups. There was no evidence that supports our 8th hypothesis because there was not a significant difference between good and bad groups for constructive behavior.

5.0 Conclusion

5.1 Summary

My dynamic CPR game is different from those in the literature because it models a real life situation. The subjects are incentivized to take out as much as they can to increase their benefit by as much as they can, but if they take to much they could end up depleting the resource. Also there is no communication in our experiment because in real life, subjects taking a resource will not be communicating because they do not know each other and most likely would not even see each other. Also my growth rate is modelled after a real life CPR because as the stock drops below 14 then the growth rate starts to slow down, also if the stock is at 32 it cannot grow anymore because of the maximum capacity of the environment. This is the same in real life because they cannot just continue to repopulate because it will get crowded in whatever environment the CPR is present.

A major finding from my experiment was that some people are able to self-govern while others are not. This means that some subjects were able to control themselves and allow the resource to last through all the rounds while others killed the resource before the end of the game. Also, to understand the differences between the good and bad groups, I tested whether there were differences in the frequency, persistence, and intensity of the subject's behavior. I was able to show that there were significant differences between the frequency of the responsible and irresponsible behavior of the good and bad groups. Also, there was visual evidence that bad groups were more persistent in their irresponsible behavior which probably lead them to kill the resource. Finally, I was able to show that the intensity of the irresponsible withdrawals was higher in the bad groups than in the good groups, meaning that the bad groups made very irresponsible withdrawals while good groups made smaller irresponsible withdrawals.

5.2 Recommendations

From my findings I propose a couple policy recommendations:

1. Put a limit on the amount that people can take out from a CPR.

By putting a limit on how much of a resource someone can take at one time, we are limiting the amount of the resource that can be taken out. In our experiment, even though we put a limit on how much the subjects could withdraw, the limit was too high and subjects were still killing the resource. I believe that the limit that should be enforced should only allow people to take out a responsible amount. Therefore we need to know how much of a CPR is left before we can set the limits. The problem with this policy action is that it is very tough to accomplish and enforce the limits. If there is no institution put in place to enforce the limits then people will still take out as much as they want. That brings me to my second policy recommendation:

2. Educate people on the dangers of CPR overuse.

This allows for no enforcement of the limits because if people were more informed on the dangers of overusing a resource they would be more responsible. Of course you will still have a few people that ignore everything and worry about themselves only, but they are the minority. I believe that if people were fully educated on why they should not take out as much as they can and should stick to the limits out in place, then they would follow the rules.

5.3 Future Experiments

Possible future experiments could be another dynamic CPR game that allows for a single communication between groups in the beginning of the game. This will allow us to test if educating the subjects on the dangers of overuse could help. It does this because if the subjects have a chance to communicate early in the game then the people that are confused and do not really understand the game will get a proper explanation of what they should do in order to preserve the resource. This could be known as the education effect, and we could see if there are any differences between the results in that experiment and the results of my experiment.

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Appendix A-Experiment Instructions

Instructions

This is an experiment in decision-making. Decisions result in monetary payoffs paid in cash at the end of the experiment. The payments are compensation for the time and effort put into making decisions. The experiment lasts about 45 minutes.

Please do not talk to others during the experiment. If you have a question, raise your hand, and an experimenter will help you.

You are going to play "The Withdrawal Game." Here is how it works:

1. You will be randomly and anonymously matched with 3 other players over the computer network.
2. You and the 3 other players will all have access to an account from which each of you can withdraw money in each of 20 rounds of decision-making.
3. Your withdrawals are important because at the end of the 20 rounds, your payoff from the game will be the sum of the amounts that you receive from your 20 withdrawals.
4. At the beginning of round 1, the account will have 32 lab dollars (LD; later converted to real money at a rate of 1 LD = 0.25 USD) in it. You and the 3 other players will individually choose how much you each withdraw from the account. You only have control over how much you withdraw. You have no control over how much the other people withdraw. You each simultaneously choose a whole number between 0 and 10 (inclusive).
5. The account balance will then become 32 LD less the sum of your withdrawal and the withdrawals of the 3 other people. You will be informed of the total amount withdrawn from the account and the new account balance.
6. The account balance will grow before the start of round 2. The amount by which the balance will grow depends on the amount in the account. Growth amounts are given by Figure 1 (see page 3). If the account has nothing in it, it will not grow. If it has 8 LD in it, it will grow by 12 LD. If it has 16 LD in it, it will grow by 16 LD, etc…
7. After the account grows by the specified amount (which depends on how much you and the other 3 people left in it), you will begin round 2, in which you and the other 3 people will make withdrawal decisions just as you did in round 1. The account will then grow again, as specified by Figure 1.
8. The process continues for 20 rounds.
9. At the end of the 20 rounds, any money left in the account is lost (kept by the experimenters).
10. If, before the end of round 20, the account has nothing left in it, advance through the remaining rounds by withdrawing 0 LD in every round.
11. As long as the sum of your withdrawal and the withdrawals of the other 3 people is no larger than the amount in the account, you will all receive your withdrawals.
12. If, in a specific round, the sum of your withdrawal and the withdrawals of the other 3 people is larger than the amount in the account, the amount in the account will be divided as follows:

a. Anyone who chose a withdrawal of a quarter or less of the amount in the account gets his/her withdrawal. Such withdrawals are deducted from the amount in the account and those people are considered "paid."
b. If and when the remaining number of people is 3, any of those 3 people who chose withdrawals of a third or less of the amount remaining in the account get his/her withdrawal. Such withdrawals are deducted from the amount remaining in the account and those individuals are considered "paid."
c. If and when the remaining number of people is 2, either of those 2 people who chose withdrawals of a half or less of the amount now remaining in the account get his/her withdrawal. Such withdrawals are deducted from the amount now remaining in the account and those people are considered "paid."
d. For any people remaining, the amount now remaining in the account is divided evenly.
e. Example: There are 18 LD in the account and the withdrawals are 2, 5, 6 and 6 LD. The person who chose to withdraw 2 LD gets 2 LD. The person who chose to withdraw 5 LD gets 5 LD. The remaining 2 people each get 5.5 LD.

13. Remember: Your earnings will be what you receive from your 20 withdrawals (converted to real money).

After the game ends, you will be asked to provide some demographic and contact information. Your final earnings will be paid to you in a private manner.

Questions?

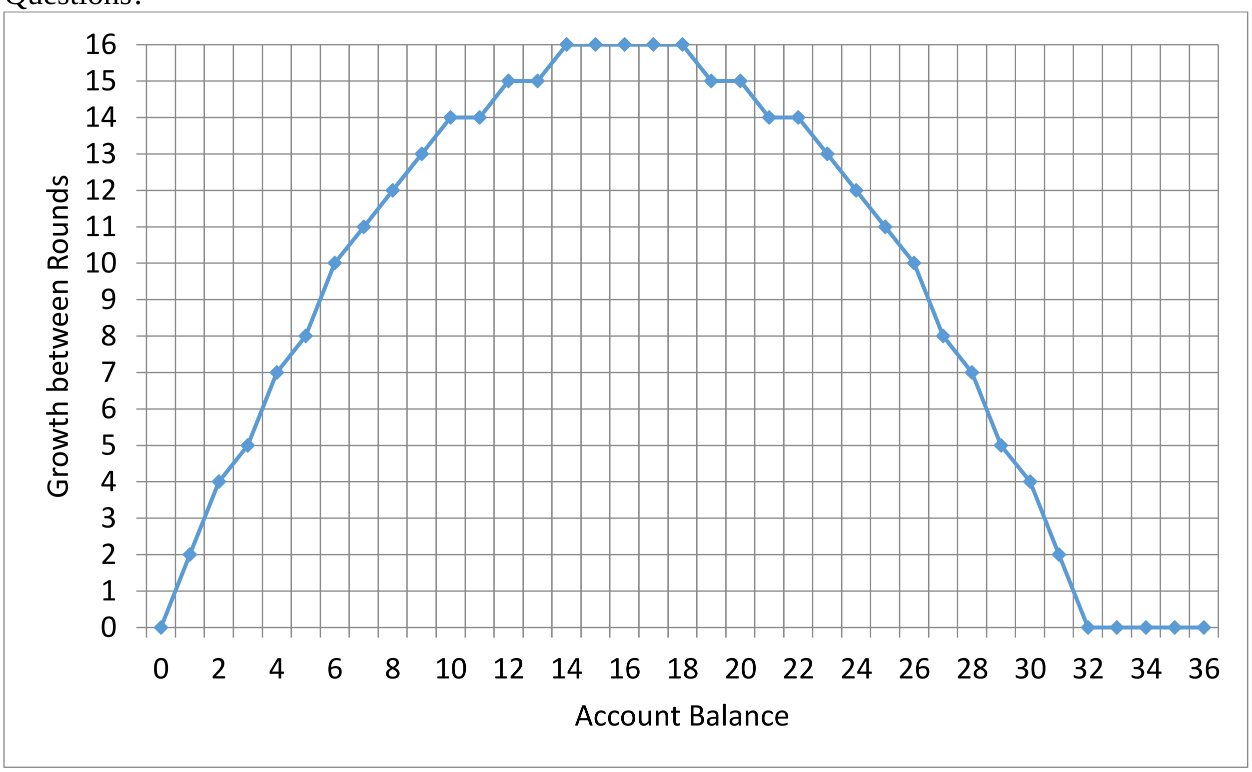
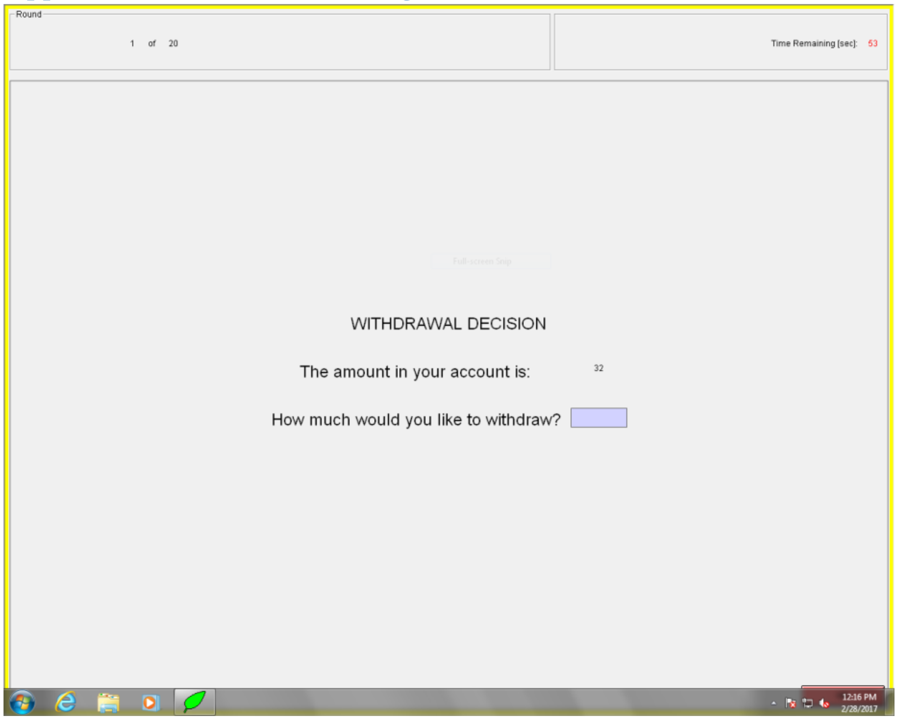


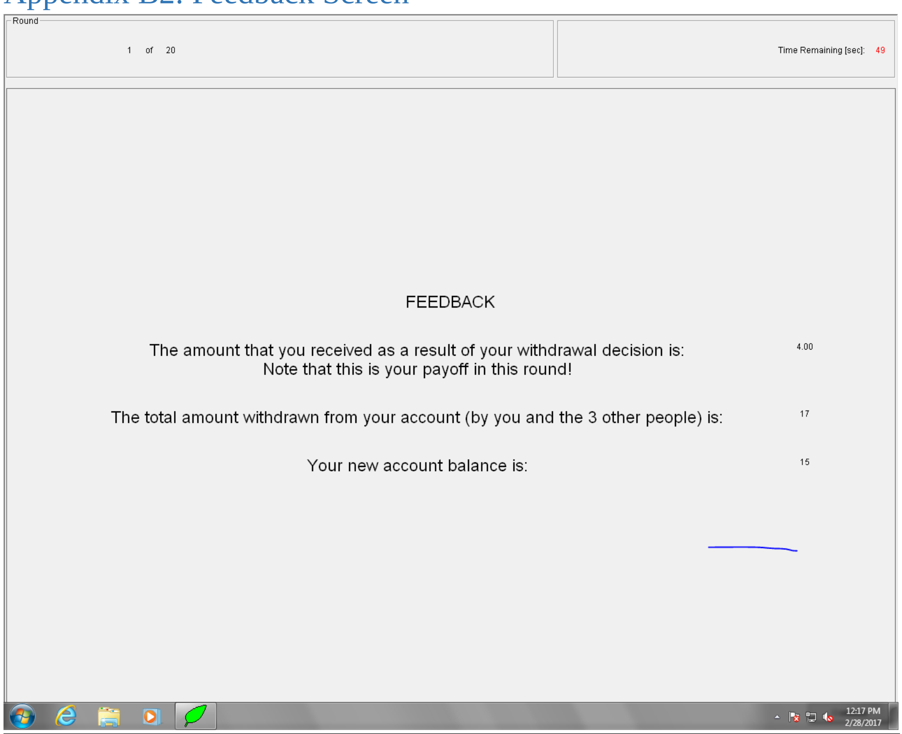
Figure 2: Account Growth between Rounds

Appendix B-Decision Screens

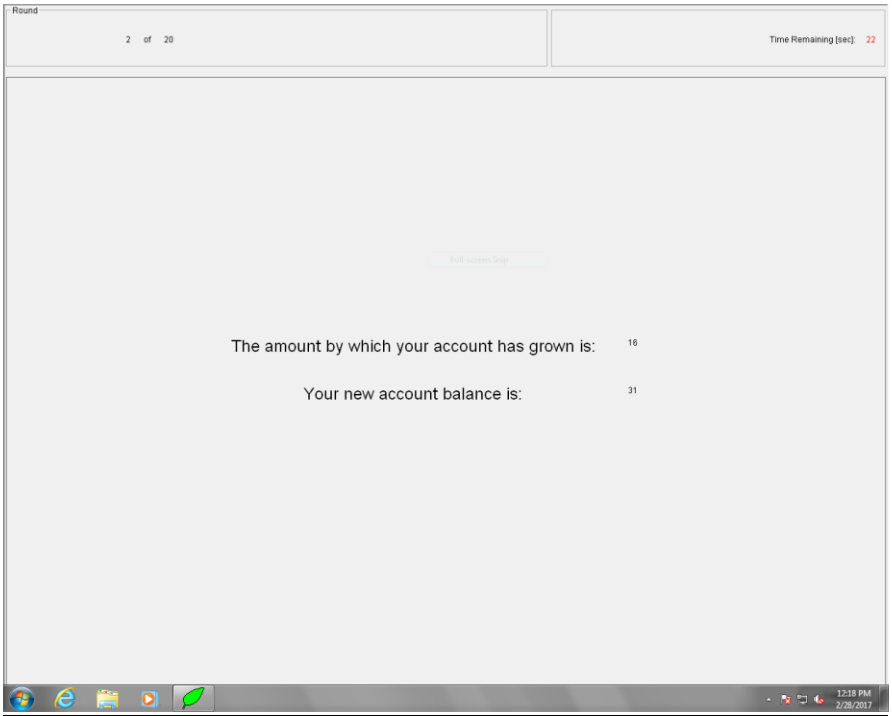
Appendix B1- Decision Making Screen



Appendix B2: Feedback Screen



Appendix B3: New Balance Screen



Appendix B4: Demographic Information