Effects of Threshold Uncertainty on Common-Pool Resources

Adler Mandelbaum, Sara E

University of California, Santa Barbara

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By SARA E. ADLER MANDELBAUM*

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Many natural and common-pool resources have inherent thresholds determining the onset of deleterious environmental impacts. Group and individual behavior were examined in an experimental setting designed to model common-pools with thresholds using three distinct treatments: one with Complete Threshold Information, one with Incomplete Threshold Information and one with Sporadically Enforced Targets. By design the true threshold was unknown to the players in the role of policymaker, and the guesses of the threshold value were allowed to change during every round. Sporadically enforced targets had a significant negative effect on the lifespan of a common-pool resource and individual gains. Allowing the participants to develop and act on their own beliefs for the location of the threshold improved both individual benefit and conservation of the common-pool. These experiments indicate that conservation of common-pool resources will be best achieved through policies which allow users of the resource access to reliable information regarding the status of the common-pool and which enable users to develop and act on their own beliefs regarding the location of threshold.
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* University of California, Santa Barbara, Department of Economics, sara.e.adler@gmail.com. Funding for this research was provided by the department of economics at UCSB. The experiment was hosted by EBEL and was implemented using z-Tree Fischbacher (1997). Thank you to Gary Charness, Zachary Grossmann, Emanuel Vespa, and Mordechai Juni for all of your advice.

I. Introduction

Common-pool Resources (CPRs) have been a focus of both economic research and governmental policy. The "Tragedy of the Commons" explains that CPRs suffer from overuse and degradation (Hardin, 1968). Establishment of effective governmental policies for conservation of CPRs are needed as without definitive intervention this diminishment will continue, especially as demands for resources increase with a growing population. The struggle for policy makers to resolve the conflict between resource conservation and growing current resource needs ultimately results in ever-changing polices. This conflict can be observed in policies addressing a variety of Common-Pool Resource (CPR) problems around the globe, including pollution and emission regulations, fisheries management, and water resources management. Polices to limit resource use are created in order to prevent disastrous environmental impacts, especially in instances where a resource may be degraded or destroyed if use passes a natural threshold. However, when the time comes for the polices to go into effect, they are unenforced due to current resource demands. This raises the question, "what are the impacts of a lack of policy target enforcement and threshold uncertainty on the lifespan of CPRs?"

This paper addresses CPRs in the context of lack of governmental commitment and follow-through which creates policies and policy targets that are constantly readjusted. In order to prevent crossing inherent natural resource and common-pool thresholds which would cause deleterious environmental consequences, governments often create policies which set resource limits or targets. However, policy makers, biased by the present and struggling to commit to the current policy, readjust the targets and limits when they are passed. There has so far been no analysis of the impact of changing policy targets and threshold uncertainty on group and individual resource use behavior and the subsequent longevity of the CPRs. The data presented here, based on a series of laboratory experiments, show that when policy targets go unenforced or are readjusted, shorter CPR lifespans result. The findings of this research are critical to addressing environmental and resource management problems and the development of more effective long term policies. This paper also has broader implications for other governmental policies and develops a case for policies which promote widespread public access to reliable information on the current condition of a CPR. This paper will demonstrate that the optimal way to conserve a CPR is to provide users of a resource access to reliable information regarding the level and status of the common-pool.

The process of repetitive threshold readjustment affects many areas of government. It is the norm for establishing the U.S governmental debt ceiling (Deb, 2011).[1] It is already happening with Corporate Average Fuel Economy Standards and is likely to be seen with the U.S. greenhouse gas emission regulations (Smith, 2011; Horowitz, 1996).[2] The consequences of this repetitive threshold readjustment have not fully been studied. Corrêa et al. (2014) examined unenforced fishing management policies and found that fishing defesos were left completely unenforced in the Brazilian Amazon.[3] The absence of enforcement led to an increase in the number of fishermen, leading in turn to a decline in fish stocks. "In short, the current [unenforced] policy is worse than no policy," (Corrêa et al., 2014).

Corrêa et al. (2014)was one of the first to examine the impacts and consequences of unenforced CPR management policy. Since the findings and results are from the Brazilian Amazon, it is important to combine their results with results from studies that are more general, enabling a broader interpretation appropriate not only to the fishing defesos of the Amazon but also to other CPRs. In other examples, such as those mentioned above, a study with field data would not be possible since the only observation is the given case; there is no counter-factual data available. This can be solved with laboratory experiments, which offer the cleanest possible approach for identifying treatment effects. A laboratory study adding to the findings of Corrêa et al. and other literature, to address moving policy targets in a general context, would have applications for many areas of CPR management. Additionally, a laboratory study can create controls and develop a

[1]Between 1995 and February 2011 the debt ceiling has been raised 12 times (Deb, 2011).

[2]"The Obama Administration will not meet its September deadline for releasing its 2025 Corporate Average Fuel Economy (CAFE) standards. The new deadline is mid-November of this year [2025]. CAFE is a national effort to increase fleet-wide vehicle fuel-economy averages to 54.5 mpg by 2025," (Smith, 2011).

[3]A fishing defeso is a type of fishing regulation which utilizes a closed season and fishing permits that require fishermen to stagger their entry, limiting the number of fishermen with access to the fishery at any one time. With defesos fishermen are also compensated during times which they do not have access to the fishery.

greater understanding of the driving factors behind CPR depletion and user behavior.[4]

To understand the impacts of changing threshold policies and threshold uncertainty, I conducted a CPR laboratory experiment in which groups of five withdraw tokens from a shared pool with a threshold for punishment, similar to an inherent threshold for environmental consequences. There were three experimental treatments, 1.) Complete Threshold Information, 2.) Incomplete Threshold Information and 3.) Sporadically Enforced Targets. In Complete Threshold Information, the punishment threshold is revealed to all participants and is automatically enforced. In Incomplete Threshold Information, the punishment threshold location is unknown to resource users. Sporadically Enforced Targets represents the real-world case in which the conflict between current and future resource use results in changing policy targets. In Sporadically Enforced Targets, guesses of the threshold location are made by a group policy maker and could be enforced before a new policy maker is assigned.

The remainder of this paper is structured as follows: The basic game and experiment will be explained in Section 2. Section 3 presents my hypotheses and theoretical predictions. Results and a discussion of the experimental findings can be found in Section 4. Conclusion and policy recommendations follow in Section 5.

A. Background

Water resources present a particularly relevant system for illustrating the interventions of policymakers and the need for a greater understanding of their impacts. As an example, Lake Kinneret provides two-thirds of Israel's water and serves as a source of water for neighboring countries in exchange for peace.[5] In an already tense region, a shortage of Israel's water resources would not only strain diplomatic relationships across borders, but would also place an undue burden on the economy and on human and environmental

[4]In Corrêa et al. (2014), through survey, they were able to determine that with unenforced fishing management policies in the Amazon the Catch Per Unit Effort (CPUE) had decreased. Since the number of fishermen had increased in addition to the decline in fish stock. Therefore, it was unclear if the decrease in CPUE is attributed to the open-access externality or the decrease in the fish stock. In a laboratory study one is able to control for resource users and would be able to effectively account for changes in effort or other user behavior attributed to changes in resource stock and changes in the number of resource users.

[5]Lake Kinneret is also known as the Sea of Galilee or Lake Tiberias.

health (Starr, 1991). Israel withdraws more water than the natural rate of replenishment, creating an annual water deficit of approximately 4,200 million cubic meters (Kislev, 2001). Since water is a basic human right, the price of water is set to near zero. The annual water deficit continues to increase as the demand for water grows and the price of water remains low (Berman and Wihbey, 1999; Plaut, 2000).

Israel's water issues can be thought of as a CPR problem based on three characteristics: (Dasgupta and Heal, 1979; Gardner et al., 1990; Sethi and Somanathan, 1996; Hardin, 1968). First, water can be withdrawn over time and is rival in consumption. The water that an individual demands and subsequently consumes cannot be utilized by any other consumer. Many stakeholders demand water from the Kinneret including but not limited to individuals, agriculture and industry across multiple countries. Second, the current amount of water which is withdrawn from the Kinneret is suboptimal (Starr, 1991; Amir and Fisher, 2006). Third, there does exist a more efficient level of water use.

To combat the depletion of water, the Israeli government created an invisible threshold, or "red line," in the Kinneret to mark a danger level for the water level.[6] In theory, if the amount of water in the Kinneret drops below this threshold, the government will take action and stop pumping water from the Kinneret to prevent saltwater intrusion and complete depletion of the resource (Feitelson and Fischhendler, 2005). However, as the water level approaches or drops below the "red line," the government shifts the threshold downward (Parparpov et al., 2013; Plaut, 2000; Feitelson and Fischhendler, 2005). As a result, consumers were not faced with penalties from the government due to the decline of the water level below the threshold, such as changes in the price of water or a decrease in water availability.

The status of Kinneret and the red line appear frequently in news headlines in Israel. "Kinneret 'Red Line' to be Lowered More" from the Jerusalem Post is an example of one the frequent headlines. This illustrates the struggle faced by the policy makers as well as the fact the red line and water level in the Kinneret are changing with no con-

[6]The natural threshold is the water level below which the Kinneret would have damaging environmental consequences, such as saltwater intrusion, and water depletion. The red line threshold was created as a warning for the natural threshold. It should not to be mistaken for the natural threshold itself.

sequence from the government. There are still societal consequences from the crossing the threshold, including changes to the ecological system and environment, challenges in changing infrastructure to account for the lower water level, and a non-optimal allocation of resources.

The original threshold was created so that future policymakers would be aware of the water shortage and impending environmental consequences for over-extraction. It was hoped that they would eventually devise a solution to the challenges of meeting the water demands of Israel and its neighbors in a sustainable manner (Feitelson and Fischhendler, 2005). Unfortunately, since the threshold was not permanently and irrevocably established, policymakers continue to repeatedly lower the threshold, deferring action on the problem to future policymakers, each time neither willing to give up consumption today nor to meaningfully address water conservation. The changing "red line" threshold demonstrates the continual conflict that faces the Israeli government as the steward of this water resource. While the government and current policymakers recognize that there is a water problem, there is a trade-off between conserving the resource with the associated costs of limiting consumption today versus the less immediate cost of depleting the resource and its value. This is the situation addressed by Horowitz (1996) with theoretical literature on governmental present biased preferences.[7] Consumers and policymakers may not know the exact point at which the value of the resource drops to nearly zero. They are tasked with balancing the conflict between consumption and conservation and devising a solution before the resource becomes valueless.

While Corrêa et al. (2014) was one of the first studies to examine a specific unenforced CPR management policy, examining a specific case of unenforced fishing policy in the Brazilian Amazon, other literature has addressed the impacts of not following through with rules and punishments in other settings (Aschuler, 2000; Bhattacharya and Daouk, 2009; Bloch, 1998; Stormshak et al., 2000). Albert Aschuler (2000) explains in his book that unenforced laws lead people to commit more crimes. Investigators in the

[7]Horowitz (1996)examined pollution emission under both a market and non-market discount rate, finding that a non-market discount rate results in governmental present preferences. This ultimately results in higher levels of pollution. This was purely a theoretical work.

fields of behavioral psychology and education have studied child performance and behavior with various parenting styles. They found that when parents do not enforce rules and their associated punishments, children exhibit more extreme and disruptive behaviors (Stormshak et al., 2000). For example, not enforcing the rules, such as continually adding more numbers to count to after “10,” is worse than not having rules. This is also supported in studies of crime and unenforced laws. Bloch in his 1998 paper compares various methods of automobile speed-control and finds that when the speed limit is unenforced, drivers exceed the speed limit more frequently and to a greater extent than the when the speed limit is enforced. Bhattacharya and Daouk (2009) show, both in a theoretical and empirical framework, that an unenforced law can be worse than having no law at all. They found that this is the case when 1.) motivation for the law is to solve a prisoner’s dilemma (if there was no law everyone would be stuck in the bad equilibrium) and 2.) some people will follow the law regardless of it being enforced.

Past CPR experiments have not examined cases of individual or group behavior when a threshold exists. Additionally, CPR experiments have not incorporated unenforced policy targets or threshold uncertainty. There have been other experiments in which individuals evaluate depletion of a CPR when there is some externality associated with the depletion. In contrast to common-pool games, many public goods games do have incorporated thresholds. Public goods games have been shown to have similar results to CPR games (Dawes, 1980; Fleishman, 1988; Sell and Son, 1997). The objective payoff that individuals receive for defecting by withdrawing from the CPR or not contributing to the public good is greater than the payoff for contributing. Additionally, if cooperation falls below a certain rate, all individuals will receive a lower payoff. Threshold public goods games have been studied, but only with a fixed threshold (Palfrey and Rosenthal, 1984; Bagnoli M, 1989, 1992). Marks and Croson (1999) examined contributions to threshold public goods under uncertainty and incomplete information. They found that the lack of information of the other group members’ valuation of the public good had no impact on contributions to or the provision of the public good. McBride (2006) examined public good contributions and determined that when there is uncertainty regarding the threshold, if the public good is low valued then uncertainty leads to fewer contributions; however, if the public good is high valued then uncertainty leads to a greater level of contributions. Based on these findings and the similarities between common-pool and public goods games, one would expect to see an impact on the levels of withdrawal as a result of the threshold uncertainty. In 2013 Barrett examined emissions abatement using a threshold public goods game both under cases of certainty and uncertainty. Under threshold uncertainty, Barrett found that individuals abate (contribute) less and individuals ignore catastrophic risks, "even when the risk is very great," (Barrett, 2013). Again, drawing a parallel between the CPR experiments and public goods games, based on the results of Barrett (2013), under threshold uncertainty individuals should withdraw greater quantities from the resource. While there are similarities between CPR experiments and public goods games, nonetheless the effects of threshold uncertainty do need to be addressed in a CPR setting. The question of unenforced policy targets has not yet been addressed in prior publications and also needs to be addressed in a CPR setting.

Some CPR experiments study the effects of uncertainty on withdrawal and depletion. However, these experiments only focus on uncertainty regarding the size of the pool (Budescu et al., 1995; Gustafsson et al., 1990). When there is uncertainty in the size of the pool, individuals overestimate the size and withdraw more coins more rapidly. Having uncertainty with the size of CPR is very similar to an unknown threshold. Therefore, based on these results, one would expect threshold uncertainty to result in an increase in threshold withdrawal. The other uncertainty seen in common-pool resource experiments is uncertainty of the payoff structure (Apesteguia, 2006). He found that individual behavior was not significantly different in the case where the exact payoff structure was revealed compared to the case where individuals were only told that their payoff would be dependent on the number of coins that they withdrew and the number of coins that others withdrew from the pool. Punishments have been examined and seen to be an effective tool in both CPR experiments and public goods games for decreasing withdrawal from the common-pool or increasing contributions to the public good (Fehr and Gächter, 2000; Nikiforakis and Normann, 2008; Ostrom et al., 1992; Wade, 1987). Gächter in his

2007 paper studied the factors which motivate voluntary cooperation through laboratory and field public goods experiments. He was able to eliminate the warm glow effect (Andreoni, 1990) and pure altruism as reasons for voluntary contribution, finding that more than half of the participants' voluntary contributions depend on the contributions of other group members. With voluntary contributors, the greater the contributions to the public good of any one individual, the greater the contributions from other members of the same group (Gächter, 2007). Gächter finds that without punishment, conditional cooperation unravels (2007). Additional threshold public goods games examined the relationship between fear, trust and individual contributions. Lack of trust and fear that others would not contribute were two of the leading causes for a lack of provision or under-provision of the public good (Rapoport, 1967; Dawes et al., 1986; Yamagishi and Sato, 1986; Parks and Hulbert, 1995; DeCremer, 1999). Another area of public goods and CPR games which has been addressed is externalities. Plott (1983), Walker and Gardner (1992) and Ostrom et al. (1992) found that individuals tend to ignore externalities, meaning that the externality had no impact on market behavior, with the resource rapidly becoming completed depleted at rates which exceed the Nash-equilibrium prediction (Andreoni, 1995).

To date, no experimental approach regarding CPRs has incorporated thresholds or unenforced policy targets. This paper addresses that gap in knowledge by identifying the relative effect of continually readjusted targets and threshold uncertainty on the longevity of a CPR through the use of laboratory experiments. Through these experiments I find that natural resources are best managed when policy makers constantly inform resource users of the level of the common pool while also making them aware that a threshold for consequences exists. I also found that there exist significant detrimental effects on the lifespans of CPRs when polices and thresholds are not enforced; unenforced, moving policy targets result in a significantly shorter common pool lifespan.

II. Experimental Design and Game Play

This experiment looks at how uncertainty with regard to the location of a threshold impacts CPR depletion. The experiment was implemented using z-Tree (Fischbacher, 1997). Sessions lasted close to an hour, including reading the Instructions aloud. Individuals were randomly assigned to a group of five and placed at their own computer terminal. Participants did not know the identities of the other members of their group or those in other groups. Instructions were given to the participants and also read aloud (see Appendix A for Instructions). Subjects were informed that they would be interacting with four other people in the laboratory.

Participants were able to withdraw up to twenty-five tokens a period from a common-pool that initially had 1000 tokens. After each period, the pool recharged as a function of the remaining tokens in the pool. When the number of tokens dropped below a certain level, 327 tokens, the recharge stopped and individuals would be faced with a penalty, the loss of $\frac{1}{3}$ of their personal tokens. The game play continued until all withdrawing group members, four individuals, could not withdraw their allotted twenty-five tokens (less than 100 tokens), or for an undisclosed amount of time.[8] The number of periods of game play represents the longevity of the CPR. After completing the experiment, individuals answered a brief questionnaire to reveal a few personal characteristics. At the conclusion of the experiment they were paid $0.025 for each token in their private fund. Using pilot study data and results from previous CPR experiments, this was calculated so that participants would receive an average of 15 dollars.

There were three different treatments in this experiment: 1.) Threshold CPR with Complete Threshold Information, 2.) Threshold CPR with Incomplete Threshold Information, and 3.) Threshold CPR with Sporadically Enforced Targets.

A. Treatment 1- Threshold Common-Pool Resource Experiment With Complete Threshold Information

In the first treatment, Threshold CPR with Complete Threshold Information, the groups were informed of the location of the threshold, the point where recharge stopped and individuals would lose one-third of their tokens. This game had four group members

[8] Time limits were not disclosed to prevent end-game effects and ensure that the experiment did not continue forever. For experimental treatments one and two, Complete Threshold Information and Incomplete Threshold Information, the time limit was 35 minutes of play. Sporadically Enforced Targets, experimental treatment three, was given 45 minutes of play. An additional 10 minutes were given to account for the actions required of the 5th player in this particular treatment.

interacting with each other (through computer terminals) and withdrawing tokens each period from a common pool and a fifth player who sat out of the round. The fifth player role rotated around the group, each player taking a turn sitting out (see Figure 1). The fifth player sat out of the round to maintain consistency with the two other experimental treatments in which the fifth player had another role. This treatment served as a control in which the true threshold and policy target was revealed and would be enforced without fail.

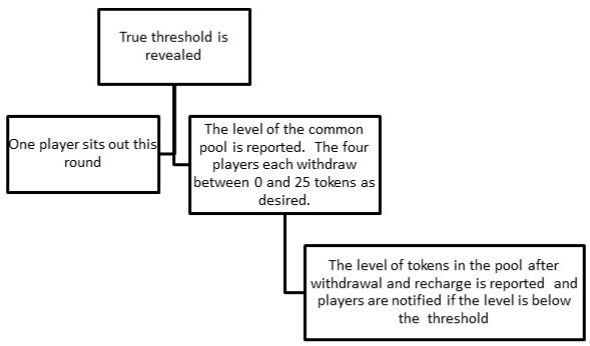

FIGURE 1.

Threshold CPR with Complete Threshold Information (experimental treatment 1). All players are informed of the true threshold. One player sits out of the round while the other four players make their withdrawal decision. After withdrawal and recharge, they all are informed of the resulting level of the common-pool.

B. Treatment 2 - Threshold CPR with Incomplete Threshold Information

In the second treatment, Threshold CPR with Incomplete Threshold Information, players were not given any information regarding the location of the threshold. They were only informed that the threshold existed. This game had four group members interacting with each other and withdrawing tokens each period and a fifth player who revealed their beliefs regarding the threshold location to the experimenter.[9] These beliefs were not shared with the other group members, but were recorded for analysis. The role of the fifth player rotated each period. Although participants were not given information about the threshold, they were given the size of the common-pool. Participants were given its

[9]Guesses of the threshold were restricted to be between the current size of the pool and zero.

initial size and then were updated on its size after withdrawal and recharge at the beginning of each period (see Figure 2). This treatment demonstrated the effects of allowing individuals and groups to develop their own beliefs of the threshold on the lifespan of the CPR when compared to the other experimental treatments, Complete Threshold Information (the control) and Sporadically Enforced Targets. This treatment not only served as a comparison against the other treatments, but its existence allowed for the development of policy recommendations.

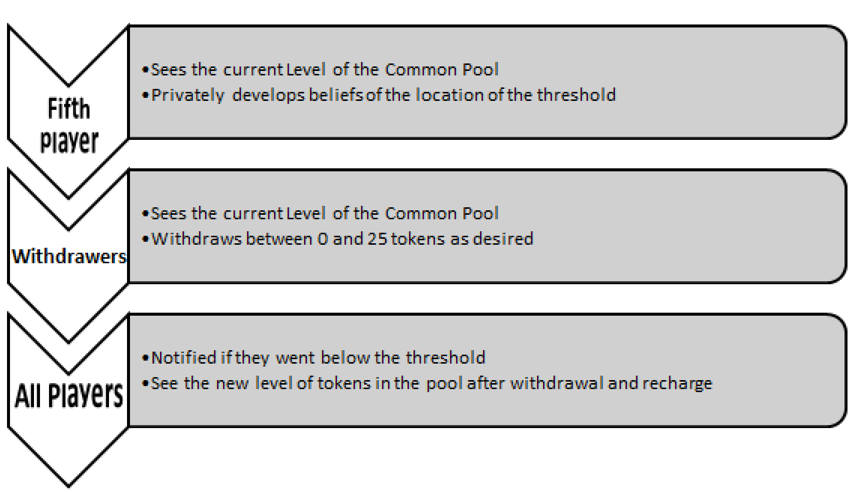

FIGURE 2.

Incomplete Threshold Information (experimental treatment 2). The fifth player develops beliefs as to the location of the threshold while the four withdrawing players are deciding how many tokens to remove from the common pool. Then, all players see the level of the common pool after withdrawal and recharge.

C. Treatment 3- Threshold CPR with Sporadically Enforced Targets

The third and final treatment, Threshold CPR with Sporadically Enforced Targets, models a moving policy target with threshold uncertainty, as described in the real world case of Israel's "Red Line". In this game the fifth member of the group played the role of the policymaker. This role rotated among the group members and was reassigned every period. At the beginning of each period the new policymaker announced to the other players their guess of the threshold, or policy targets, via the software program.

The other four members then withdrew tokens as in the other two experimental treatments. After withdrawal and recharge, the policymaker was informed of the level of the common-pool, reminded of their guess of the location of the threshold, and then given an option of enforcing their guess. The policymaker could pay 100 tokens to the common-pool to enforce their guess of the threshold and inflict a punishment on all the players. The punishment was a loss of 50 tokens from the private funds of the four withdrawing players (see Figure 3). The changing policy targets in this treatment, as well as the ability to leave the policy targets unenforced, represented real world CPR situations, as illustrated in the Introduction.

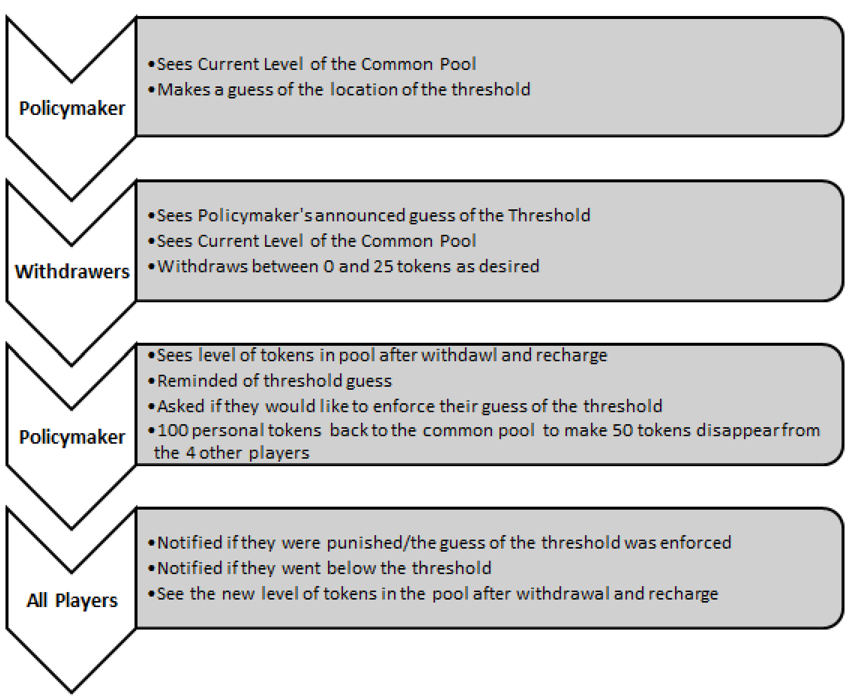

FIGURE 3.

Sporadically Enforced Targets (experimental treatment 3). The fifth player, the policymaker, makes an announced guess of the threshold. The four with drawing players see the current level of the common pool and withdraw their desired tokens. The policymaker can then enforce their guess of the threshold. After the policymaker makes their enforcement decision all players see the level of the common pool after withdrawal, token contribution and recharge and they are notified it they were punished by the policymaker or if they went below the threshold.

D. Rationale

The punishment threshold was designed and implemented to represent the crossing of an environmental threshold as well as the associated reduction in welfare and well-being. Sporadically Enforced Targets was designed to closely match moving policy targets resulting from the conflict between future resource use and bias for the present, as illustrated in the example of the moving punishment threshold ("red line") in Israel's main body of water. The rotating role of the policymaker and the existence of a cost to punish and enforce the estimated threshold represent the conflict for the policymaker of conservation, facing a cost today, versus uncontrolled consumption. Just as in the real world case, the policymaker has the option to do nothing and pass the responsibility to the next policymaker, which by not addressing over-consumption would jeopardize the life of the common-pool. Since enforcing this punishment is costly and the role of policymaker will move to another player next period, the announced target or guess of the threshold will move and the policymaker may choose to pass the responsibility of enforcement to policymakers in future rounds. Alternatively, one could enforce the predicted threshold or target to prevent individuals from withdrawing too many tokens, which otherwise could result in ending the game more quickly and a large loss of personal tokens. If the punishment is enacted, then the public good is increased. [10]

III. Hypothesis and Theoretical Predictions

In this section I present theoretical predictions for individual and group behavior in this experiment, as well as my hypotheses based on said predictions and previous findings in the literature. I will discuss the optimal social planner solution and explain the conditions under which that method of withdrawal will be sustainable as a Nash Equilibrium. I will also introduce the Pareto inferior Nash equilibrium. Using a model, predictions will be made about withdrawal and the level of the CPR under threshold uncertainty. A

[10]There are other reasons why a participant in the role of the policy maker would choose to not enforce their guess, but either way the result is the same. The target or announced guess of the threshold changes with each policy maker and if the target goes unenforced it will appear like the moving "red line" and other unenforced and constantly readjusting CPR management policies.

discussion of my hypotheses will follow.

The optimal social planner solution for token withdrawal is a strategy of alternating between 58 and 55 tokens, an average of 57 tokens each period (see Figure 4).[11] This is the greatest level of withdrawal which recharges the common-pool to full capacity. If participants continue to withdraw at this level, the common-pool continually gets recharged to full capacity while adding the maximum tokens to one's private fund. The CPR remains full and the game could go on forever in this fashion without crossing the threshold. Individuals within the group withdrawing on average 14.5 and 13.75 tokens in an alternating manner is a Nash equilibrium solution.

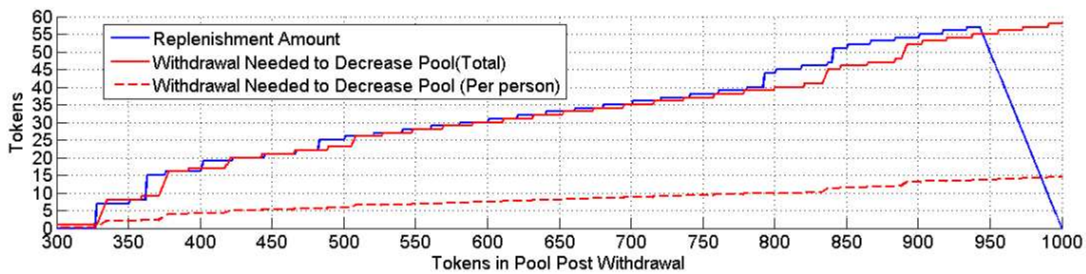

FIGURE 4.

Based on the recharge function, this graph displays the number of tokens which will be added back to the common-pool after withdrawal (in blue). Taking recharge into account, it also displays the total number of tokens that need be withdrawn from the common-pool in order for the pool to have fewer tokens the next round (in red).

Any strategy of taking out a greater number of tokens than the efficient amount (58 and 55 tokens) would result in a reduction in total earnings. After taking out more than the optimal amount, one would have to decrease withdrawal for several periods to prevent

[11]In a one hour session the greatest number of periods that one could play is approximately 200 periods. If one were to look at the optimal solution for the similar 200 period finite threshold CPR game, just as in the infinite game described in this paper, it would be to alternate between 58 and 55 tokens. Since the game is finite one would only do this for the first 188 periods. In period 189 the average group withdrawal would be 95 and then everyone would withdraw their full token allotment of 25 tokens, for a total group withdrawal of 100 tokens in the last ten periods. This results in an overall average withdrawal of 58.9. For the 200 period finite game Threshold CPR game this solution would ensure that that threshold would not be crossed and the game would last all 200 periods, both of which make sure that all participants' total tokens are maximized. Alternating between 58 and 55 tokens for the majority of the game results in the maximum number of tokens deposited in individuals private funds for the maximum number of periods both in finite and infinite games.

crossing the threshold, losing a significant fraction of one's tokens, and limiting game play. This decrease would offset any gain caused by the initial increase in withdrawal. For example, if the group were to withdraw 100 tokens in the first period, instead of the optimal 58, in order to prevent crossing the threshold the group would have to withdraw only 40 tokens in each of the next twelve periods. In the first period the group would increase their earnings by 42 tokens, but as a result of the reduction in withdrawal over the following twelve periods it would cost the group a total of 198 tokens. The initial increase in token withdrawal would not have a net benefit in terms of overall payoff. This is true for all strategies other than the alternating 58 and 55 tokens. With the optimal solution the pool initially decreases when 58 tokens are withdrawn, but it is then immediately refilled the next period when only 55 tokens are withdrawn. Although the threshold would not be crossed if any fewer than 58 or 55 tokens are withdrawn, this is a non-optimal solution since a greater number of tokens could have been placed in all individuals' private funds by increasing withdrawal.

While the optimal social planner solution is to withdraw 58 and 55 tokens in an alternating manner, the best response to the other group members withdrawing their full endowment is for one to also withdraw their full endowment. This does ultimately deplete the common-pool and results in the group crossing the threshold, but under the condition that the other group members are all withdrawing their full endowment, withdrawing one's full endowment maximizes one's total payoff. All players withdrawing their full endowment and depleting the resource is a Pareto inferior Nash equilibrium.

According to the theoretical model developed by Diekert (2014), when the threshold is known, maintaining the socially optimal level of withdrawal and not crossing the threshold is dependent on the discount factor. When the threshold is sufficiently close to the size of the common-pool, meaning that a large amount of the resource will have to be given up in order to make sure that the threshold is not crossed, then the first-best outcome will be to cross threshold and deplete the resource. If the threshold is sufficiently close to zero, then the first-best solution is to withdraw exactly the amount which does not cause the threshold to be crossed. How much one values the present or the future, one's discount factor, will determine what *sufficient* means. From Diekert (2014) the minimum discount factor, β, needed to maintain the efficient, socially optimal solution is given by

$$\bar{\beta} = 1 - \frac{u\left(\alpha^i T\right)}{u\left(R - \frac{N-1}{N} T\right)},$$

where T is the Threshold, α^i is an individual's share of the common-pool, R is the CPR size, and N represents the number of individuals. Using this equation, as long as the discount factor is greater than 0.89, the social planner level of withdrawal, alternating between 58 and 55 tokens, should be able to be sustained when the threshold is known. In this experiment the discount factor is 1. Since $\beta = 1 > \bar{\beta} = 0.89$, the social planner solution is a Nash equilibrium and can be sustained.

The social planner solution mentioned above, alternating between 58 and 55 tokens, is a possible solution when the threshold is unknown. When making withdrawal decisions the benefit from increasing withdrawal beyond that level must be balanced against individuals' beliefs that the threshold will be crossed. I will again refer to the theoretical model developed by Diekert (2014) for when the threshold is unknown in a CPR. The boundaries on aggregate extraction (without the recharge) are defined by the equations, $\underline{s}$ and $\bar{s}$, given below.

$$\underline{s} = max\left\{0, \frac{((1-\beta)N+\beta)R-3\beta R}{(1-\beta)N}\right\}$$

$$\bar{s} = min\left\{\frac{((1-\beta)N+\beta)R}{(1-\beta)N+3\beta}, R\right\},$$

,where β is the discount factor, N is the number of individuals, and R is the size of the resource. Using the parameters of this experiment, the first-best theoretical boundaries on aggregate extraction without recharge are [0,333.33]. This means that the predicted first-best common-pool level for Incomplete Threshold Information is between 1,000 tokens and 666.66 tokens or at the depletion equilibrium.

Although the theory does predict that groups will avoid crossing the threshold, these predictions should be used merely as a comparison between how the Complete Threshold Information groups and Incomplete Threshold Information groups will behave. It is hypothesized, based on previous CPR experiments, that groups will deplete the CPR. The question is, under the different experimental treatments, how many periods will the resource last?

The three experimental treatments present various options to enable an evaluation of the use and consequences of thresholds in the setting of a CPR. The expected result is that being given information which is constantly changing and unenforced, like the "red line" in the Kinneret in Israel (Threshold CPR with Sporadically Enforced Targets), will result in the resource being depleted more quickly than the cases for which there is either no announced threshold (Threshold CPR with Incomplete Threshold Information) or a threshold that is announced (Threshold CPR with Complete Threshold Information). This follows from previous literature, like that of Corrêa et al. (2014), Bloch (1998), Bhattacharya and Daouk (2009), and Stormshak et al. (2000), where unenforced rules and regulations were found to result in more extreme and negative behaviors. This hypothesis is also drawn from studies which found that uncertainty results in common-pools being depleted more rapidly (Budescu et al., 1995; Gustafsson et al., 1990). Additionally, the results of Barrett's threshold public goods game add to the justification of the hypothesis that Threshold CPR with Sporadically Enforced Targets will have a shorter common-pool lifespan than Threshold CPR with Incomplete Threshold Information or Threshold CPR with Complete Threshold Information. Since Barrett's results showed that uncertainty resulted in fewer contributions to the public good and players ignoring catastrophic events, it is predicted that the threshold and policy targets in a common-pool will also be ignored, leading to the depletion of the resource.

Based on the theoretical predictions above and the studies on uncertainty, it was hypothesized that the uncertainty associated with the threshold in Incomplete Threshold Information will result in more tokens being withdrawn and the CPR being depleted more rapidly than in the Complete Threshold Information treatment. It is therefore hypothesized that providing participants with the true threshold information will result in the CPR lasting for the greatest number of periods. With the extra level of uncertainty in Sporadically Enforced Targets, from both the target and the threshold, it follows that the

CPR will be depleted more quickly than the other two experimental treatments. Individuals will have to weigh the benefit of increasing their withdrawal above the safe group level, 58 or 55 tokens, against the potential cost of crossing a policy target and having it enforced in addition to the possibility of crossing the threshold.

It was also hypothesized that policy makers would not enforce their policy targets (guesses of the threshold). This also follows from the results of Barrett. Since the consequences of crossing the threshold would likely be ignored, individuals would not enforce their policy targets. Another justification is that since the cost of punishment is great and the role of the policy maker rotates, participants would not enforce their policy targets and would instead leave the role of enforcement to the next policy maker.

- ***Hypothesis 1: Providing participants with the true threshold information will result in the Common-Pool Resource lasting for the greatest number of periods.***
- ***Hypothesis 2: Announcing a policy target which is unenforced will result in the Common-Pool Resource being depleted more quickly than when individuals are provided with complete threshold information or incomplete threshold information.***

IV. Results and Discussion

The experiment was conducted at the University of California, Santa Barbara's Experimental and Behavioral Economics Laboratory. There were 180 participants from the University of California, Santa Barbara's undergraduate population. In each experimental treatment, there were 12 groups, each consisting of 5 members. Average earnings were approximately $15, including a $5 show-up fee.

The results section is divided into four sections. I begin by discussing the *Lifespan of the Common-Pool Resource* across the three different experimental treatment groups. I then support my findings by examining the *Total Token Withdrawal From the Common-Pool Resource*. Next, I discuss the *Over Withdrawal and Depletion* of the common-pool. Finally, in *Pre-Threshold and Post-Threshold Behavior* individual withdrawal behavior before the threshold is crossed is compared to their post-threshold behavior. There are four major results:

- ***Sporadically Enforced Targets, when non-credibly enforced, results in a significantly shorter common-pool lifespan.***
- ***A greater number of tokens is indicative of a greater number of periods of game play.***
- ***Sporadically Enforced Targets results in a significantly fewer number of individual tokens upon the completion of the game.***
- ***The majority of groups withdrew tokens in excess of the optimal strategy.***

A. Lifespan of the Common-Pool Resource

In these games, extending the number of rounds played serves as a measure of conservation of the CPR. Table 1 displays the number of periods that the game lasted, the longevity of the common-pool.

In all three experimental treatments there was one group which was considered sustainable.[12] The sustainable groups were withdrawing close to the optimal amount of tokens, an average of 57 total tokens or less.[13,14] This resulted in the common-pool remaining in the 900-1000 token range for the majority of the game, removing a few tokens each round and then getting recharged with very little downwards motion. Continuing this process, these groups would be able to play indefinitely, creating a sustainable resource.

The average number of periods of play, including only the non-sustainable groups, was 51, 45.6 and 29.9 for the Complete Threshold Information, Incomplete Threshold Information and Sporadically Enforced Target experimental treatments, respectively. The time paths of the common-pools for the three treatments are presented in Figures 5 - 7.

[12]The sustainable groups are denoted with an asterisk (*) in Table 1.

[13]The Social Planner Optimal Strategy is alternating between withdrawing 58 tokens and 55 tokens, averaging 57 tokens throughout the game.

[14]The optimal number of tokens was calculated using the recharge function. This is the greatest amount of tokens which can be withdrawn while allowing the common-pool to get recharged at the maximum amount and continue to remain full.

TABLE 1—EACH NUMBER REPRESENTS THE NUMBER OF PERIODS OF GAME PLAY BEFORE THE COMMON POOL WAS DEPLETED. THE ASTERISK (*) DENOTES GROUPS WHICH WERE CONSIDERED SUSTAINABLE AND DID NOT DEPLETE THE COMMON POOL. THE CROSS (+) DENOTES THAT THE AVERAGE EXCLUDES THE SUSTAINABLE GROUPS.

Longevity of Common-Pool By Treatment: Number of Periods of Play		
Threshold CPR with Complete Threshold Information	Threshold CPR with Incomplete Threshold Information	Threshold CPR with Sporadically Enforced Targets
14	20	21
19	21	23
24	23	25
25	24	25
31	24	25
41	25	25
43	26	28
43	36	33
54	88	33
67	106	33
200	109	58
∞*	∞*	∞*
Average : 51^{+}	45.6^{+}	29.9^{+}
Standard Deviation : 51.9	36.2	10.2

Since the variable of interest, the number of periods until depletion, is at the group level, counting this event results in a very small number of observations, yielding only twelve observations in each experimental treatment ranging from values of fourteen to 200 as well as three sustainable groups. Therefore the data was sorted into bins for further evaluation, which limits the effect of variation in the data. The bins were determined by quartiles. The data was given a value of 1if it fell in the first quartile, 2 if it fell in the second quartile, and so on. The sustainable groups, however, were collected into a fifth bin and given value of 5 to distinguish them from the groups which depleted the resource.

After putting the data into bins, subgroup analysis was conducted. The case of interest was the one where there was no credible enforcement of the guess of the threshold. Of the twelve groups who played Sporadically Enforced Targets, six fall into the category of non-credible enforcement, punishing the other members of their group one time or less (four groups did not punish at all and two groups only punished once) and six fall into the category of credible enforcement. Those groups which made credible threats of punishment, as defined by punishing two or more times, punished throughout the game–in early rounds and then in later rounds as well.

One-tailed Mood's median tests were performed to test the hypotheses that the treatment samples were drawn from populations with equal medians.[15] ,[16] Results comparing each treatment group to each other, including the subgroups, are summarized in Table 2. A median test was conducted comparing the non-credible enforcement subgroup to the credible enforcement subgroup, resulting in a fisher exact p-value of 0.008, indicating that there is a significant difference in the longevity of the CPR between credibly enforced and non-credibly enforced subgroups from the Sporadically Enforced Targets experimental treatment. The sustainable group fell into the credible enforcement subgroup. Subgroup analysis was carried out using the two distinct Sporadically Enforced Targets subgroups. Conducting a median test on Threshold CPR with Incomplete Threshold Information against the non-credible enforcement subgroup of Sporadically Enforced Targets yielded a fisher exact p-value of 0.092; there is a significant difference between the two treatments' common pool lifespans at the 10% level. When the policymakers from Sporadically Enforced Targets made credible threats of enforcement of their guesses, there was no significant difference between any of the treatments; median tests resulted in Fisher Exact p-value of 0.439 when conducted against Threshold CPR with Complete Threshold Information and Threshold CPR with Incomplete Threshold Information. There is no significant difference between Threshold CPR with Complete Threshold Information and Incomplete Threshold Information, with a chi-squared value of 0.6667 with one degree of freedom and a p-value of 0.414. Comparing Complete Threshold Information to the non-credible enforcement subgroup yielded results which were significantly different, Fisher Exact p-value of 0.025. Enforcement makes a difference. There was no significant difference between Complete Threshold Information and Sporadically Enforced Targets when credibly enforced, but a significant difference

[15]This test was chosen since it is a non-parametric test and it handles data that has large observations, like the sustainable groups, particularly well (Siegel, 1956). One-tailed tests are justified by my hypotheses.

[16]Lemeshko and Chimitova (2007)showed there are "no evident problems" with testing hypotheses using non-parametric tests in cases of grouped data.

when non-credibly enforced. Threshold Information and the credible enforced subgroup of Sporadically Enforced Targets, Fisher Exact p-value of 0.439.

TABLE 2—RESULTS OF MEDIAN TESTS. ONE-TAILED MOOD'S MEDIAN TESTS WERE PERFORMED ON THE BINNED DATA TO TEST THE HYPOTHESES THAT THE TREATMENT SAMPLES WERE DRAWN FROM POPULATIONS WITH EQUAL MEDIANS.

	Threshold CPR with Complete Threshold Information	**Threshold CPR with Incomplete Threshold Information**	**Threshold CPR with Sporadically Enforced Targets: Credibly Enforced**	**Threshold CPR with Sporadically Enforced Targets: Non-Credibly Enforced**
Threshold CPR with Complete Threshold Information	-	Fisher exact p-value=0.414	Fisher exact p-value=0.439	Fisher exact p-value=0.025
Threshold CPR with Incomplete Threshold Information	Fisher exact p-value=0.414	-	Fisher exact p-value=0.439	Fisher exact p-value=0.092
Threshold CPR with Sporadically Enforced Targets: Credibly Enforced	Fisher exact p-value=0.439	Fisher exact p-value=0.439	-	Fisher exact p-value=0.008
Threshold CPR with Sporadically Enforced Targets: Non-Credibly Enforced	Fisher exact p-value=0.025	Fisher exact p-value=0.092	Fisher exact p-value=0.008	-

As long as threshold information was available that could be relied upon when making one's withdrawal decision, either from one's own beliefs or given from a policymaker, there was no negative effect on the life of the CPR. However, being given extra information in some cases can become detrimental to the life of the common-pool.In the case of Threshold CPR with Sporadically Enforced Targets, when the policymakers shared their guess of the location of the threshold, the extra information may crowd out the individual responsibility to develop players' own beliefs. It appeared that each participant only made their guess every fifth turn when they were assigned the role of the policymaker. When the policymakers did not enforce the guess, having developed no belief of their own, the participants were left with no information which they believed to be credible when making their decision for how many tokens to withdraw. This is a possible explanation for the significant difference between Threshold CPR with Incomplete Threshold

Information and Threshold CPR with Sporadically Enforced Targets, especially when looking at the groups faced with non-credible enforcement.

With Incomplete Information, individuals developed their own beliefs, being told only that there is a threshold of negative consequences and individuals were prompted to guess on their own by telling the experimenter their guess when not withdrawing, but never sharing it with the group. Those groups in Sporadically Enforced Targets which made credible threats of punishment had information which had to be taken as reliable or risked getting punished again in the future.[17] The groups in Sporadically Enforced Targets which did enforce their guesses, through punishment and credible threats of punishment, relied upon the information which they were given, the guesses of the threshold (targets), and used that to determine how many tokens to withdrawal each period. Not having information which one could rely upon resulted in a significant reduction in the number of periods of game play and the lifespan of the CPR.

Lack of trust is one of the main causes of under-provision of public goods and would therefore imply that lack of trust in a CPR setting would lead to a greater level of withdrawal and a shorter common-pool lifespan (Rapoport, 1967; Dawes et al., 1986; Yamagishi and Sato, 1986; Parks and Hulbert, 1995; DeCremer, 1999). While trust was not directly measured, the constant lowering of targets and announced guesses combined with non-credible enforcement would be a strong contributor to a general lack of trust within Sporadically Enforced Target groups.

Interestingly, there was no benefit in terms of the length of the life of the CPR from giving participants the additional information as to where the true threshold was located. While this is counter-intuitive and conflicts with the hypothesis, it can be attributed to some individuals having present biased preferences. Individuals knew of the level of 327 as threshold, but appeared unwilling to give up tokens in the current round and continued to withdraw tokens at higher than optimal levels, likely thinking that they would withdraw fewer tokens the next period as they moved closer to the threshold and

[17]This is consistent with the punishment literature which shows that when implemented, punishment is effective at conserving a common-pool resource (Fehr and Gächter, 2000; Nikiforakis and Normann, 2008; Ostrom et al., 1992).

to the pending punishment. Every period players went through the same thought process, opting to maximize their private fund in the current period and withdrawing more than the optimal amount of tokens, in hopes of conserving the CPR the next period. The benefit of additional information could be canceled out by individuals' present biased preferences and the knowledge that they have time in the future to take fewer tokens before hitting the threshold. This explains not only why there may not be any added benefit from Complete Threshold Information over Incomplete Threshold Information, but it also can give another reason as to how the CPR is depleted in under full information.

Although the hypothesis that Complete Threshold Information would have the greatest common-pool lifespan was not confirmed, other hypotheses were proved accurate within this experiment. Threshold Information Sporadically Enforced Targets, when non-credibly enforced, had a significantly shorter common-pool lifespan than the other two experimental treatments. The hypothesis that the common-pool would be depleted was shown to be correct, in contrast to the theoretical predictions, with 33 of 36 groups depleting the CPR.

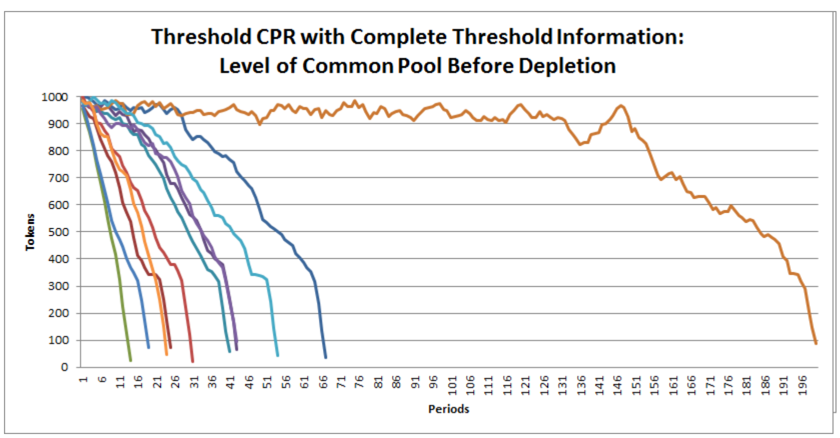

FIGURE 5.

Level of tokens remaining in the common pool each period, by group, before the common pool is depleted under Complete Threshold Information.

- ***Result 1. Sporadically Enforced Targets, when non-credibly enforced, results in***

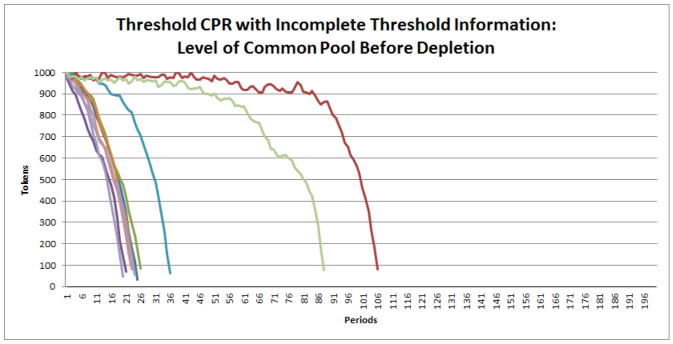

FIGURE 6.

Level of tokens remaining in the common pool from each period, by group, before the common pool is depleted under Incomplete Information.

a significantly shorter common-pool lifespan. Common-Pool Resource lifespans increase by providing individuals with reliable information about the current size of the resource and the location of the threshold (their own beliefs or given information).

- ***Hypothesis 1: Providing participants with the true threshold information will result in the Common-Pool Resource lasting for the greatest number of periods. This could not be supported. Providing resource users with any threshold information is sufficient to increase the common-pool resource lifespan.***
- ***Hypothesis 2: Announcing a policy target which is unenforced will result in the Common-Pool Resource being depleted more quickly than when individuals are provided with complete or incomplete threshold information. This was shown to be true.***

B. Token Withdrawal from the Common-Pool Resource

Examining the total token withdrawal by individuals at the completion of the game reveals a strong positive correlation, r = 0.8175, between earnings and lifespan of the common-pool (see Figure 8). To make sure that post-threshold behavior and the punishment was not playing a major role, the pre-threshold relationship was also examined. This, too, showed a strong positive correlation with r = 0.8253(see Figure 9).

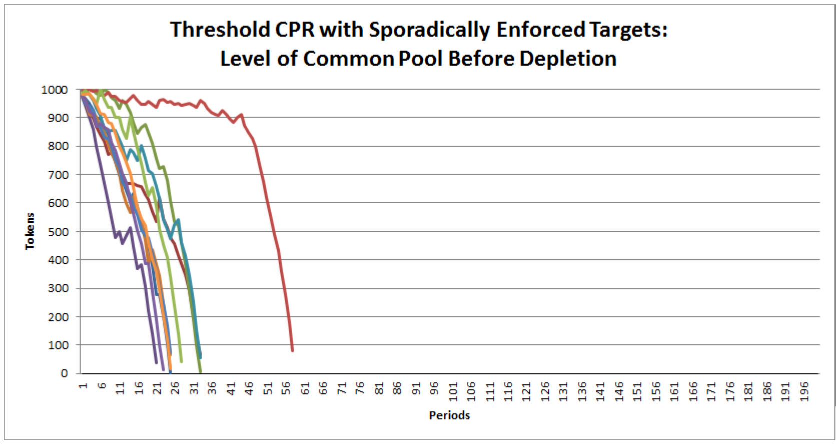

FIGURE 7.

Level of tokens remaining in the common pool from each period, by group, before the common pool is depleted under sporadically enforced targets.

TABLE 3—SUMMARY OF INDIVIDUAL TOTAL TOKEN WITHDRAWAL BY EXPERIMENT.

Summary of Individual Total Tokens		
	Mean	Standard Deviation
Threshold CPR with Complete Threshold Information	541.7	699.8
Threshold CPR with Incomplete Threshold Information	409.0	307.5
Threshold CPR with Sporadically Enforced Targets	239.3	138.7

The longer the lifespan of the common-pool, the more opportunities to earn tokens. From this, one can infer that earning more tokens is indicative of increased lifespan of the common-pool.

As verification, all individuals were placed in bins according to the length of game play. The top earners who played the most periods were compared to the top earners who played the fewest periods, with average earnings of 1498.5 and 236.4 respectively. These two groups were compared using a rank sum test, resulting in a test statistic of -4.828, which is significant at the 1% level. This shows that the top earners did come from the groups who played the greatest number of periods and were able to maximize the lifespan of the common-pool. Therefore, one is able to conclude that more tokens also represent a longer lifespan of the CPR.

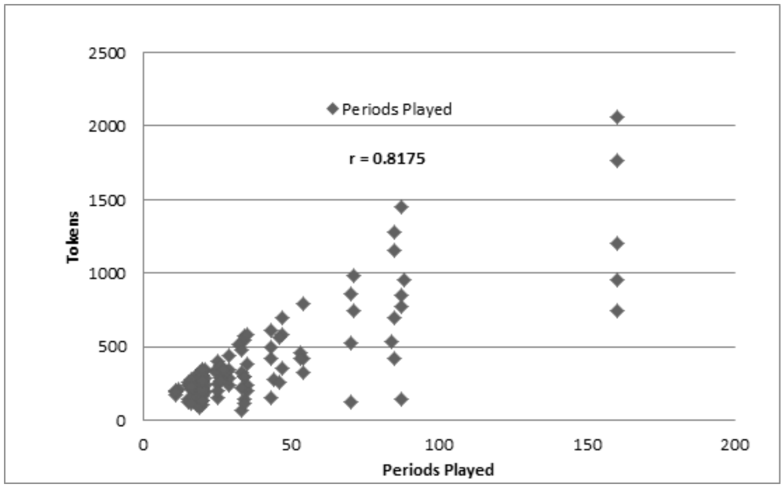

FIGURE 8.

Scatter Plot showing the strong positive relationship, r = 0.8175, between total tokens earned per individual at the end of the game and Periods played. (N=130)

All players' total token withdrawal is another tool for comparing the lifespan of the CPR under the various conditions of the different treatments. The average total token withdrawal by treatment can be seen in Table 3. Even with a larger sample size, normality cannot be assumed (see Figure 10) so the Wilcoxon Rank-Sum test, a non-parametric test, was used to compare total tokens across the different treatments (Siegel, 1956). Conducting a Rank-Sum test on the Complete Threshold Information level of total tokens against the Sporadically Enforced Targets level of total tokens generated a test statistic of z = 3.328; Sporadically Enforced Targets had significantly fewer total tokens than Complete Threshold Information at the 1% level (p-value = 0.0009). A Rank-Sum test on the Incomplete Threshold Information level of total tokens against the Sporadically Enforced Targets level of total tokens yielded a test statistic of z = 3.052 and found that Sporadically Enforced Targets had significantly fewer total tokens than Incomplete Threshold Information at the 1% level (p-value = 0.0023). A Rank-Sum test on the Incomplete Threshold Information level of total tokens against the Complete Threshold Information level of total tokens results in a test statistic of z = 0.192, confirming our earlier results that there is no significant difference between Complete and Incomplete

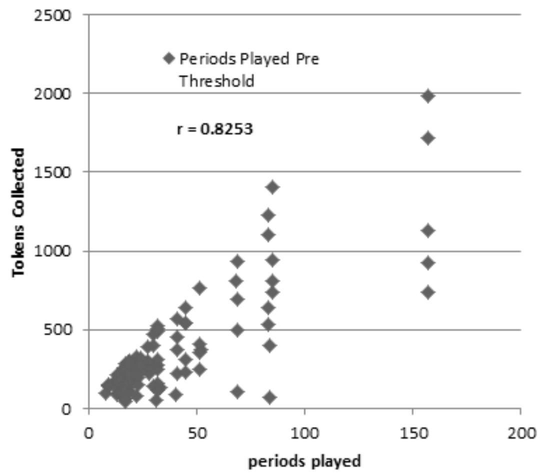

FIGURE 9.

Scatter Plot showing the strong positive relationship, r = 0.8253, between total tokens earned per individual the last period before crossing the threshold and periods played. (N=130)

Threshold Information (p-value = 0.8481).

Since those who played the Sporadically Enforced Targets earned fewer tokens and fewer tokens are indicative of a shorter CPR lifespan, these findings support the previous result that Sporadically Enforced Targets results in a reduction of the lifespan of a CPR. The Complete Threshold Information common-pool lifespan had no significant gains over Incomplete Threshold Information. Information regarded as reliable whether provided or based on one's own beliefs presents no harm to the life of the common-pool. All information which is perceived as reliable has significant gains over sporadically enforced targets.

Not only do these results support previous findings, but they also support experimental hypotheses. Those who played Sporadically Enforced Targets earned fewer individual total tokens than those who played under Complete Threshold Information or Incomplete Threshold Information. Since a greater number of tokens is indicative of a greater number of periods of game play, this shows that those who played Sporadically Enforced Targets played a fewer number of periods.

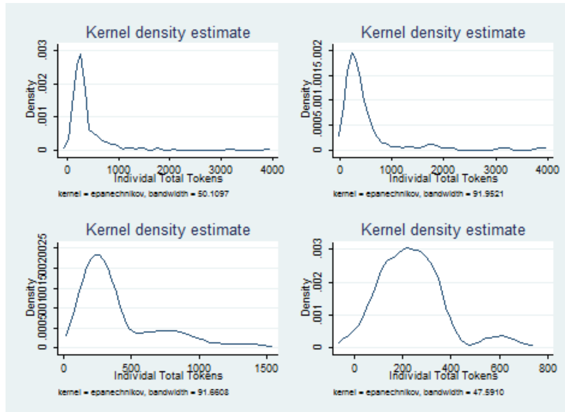

FIGURE 10.

Distribution of Individual Total Tokens showing the distribution of total tokens earned is positively skewed for all groups. The top left graph displays the distribution for all groups. The top right graph displays the distribution for groups under Complete Threshold Information. The bottom left graph displays the distribution for groups under Incomplete Threshold Information. The bottom right graph displays the distribution for groups under Sporadically Enforced Targets.

- ***Result 2. A greater number of tokens in players' private funds is indicative of a greater number of periods of game play.***

- ***Result 3. Sporadically Enforced Targets results in a significantly fewer number of individual tokens upon the completion of the game, when compared to both Complete and Incomplete Threshold Information. Combining these findings with Result 2, Result 1 is further supported. Therefore, not only do individual earnings increase by providing individuals with reliable information about the current size of the resource and the location of the threshold (given information or their own beliefs), but CPR lifespans increase as well.***

C. Over Withdrawal and Depletion

Despite the theoretical predictions, the majority of all groups, 77.7%, over extracted the resource compared to the optimal level, withdrawing more than the optimal amount of 58 and 55 tokens. The average amount of withdrawal was 66.5 tokens per period (see Table 4). Half of the groups given Complete Threshold Information withdrew more than the optimal level. The average withdrawal was 61.7 tokens and was just over the 57 average optimal tokens. This is in contrast to the theoretical predictions, which posited that since the discount factor was greater than 0.89, the socially optimal level of withdrawal would be able to be sustained. Under Completed Threshold Information only one group failed to cross the threshold, withdrawing close to the socially optimally level. It was hypothesized that the common-pool lifespan for Incomplete Threshold Information would be significantly shorter than under Complete Threshold Information. The model from (Diekert, 2014) predicted that the common pool level would be greater than 666 tokens. Incomplete Threshold Information had an average withdrawal of 66.5 with 88.3% of groups on average over withdrawing. As with Complete Threshold Information, only one group from Incomplete Threshold Information failed to cross the threshold. This treatment did have a greater average level of withdrawal and a greater percentage of group withdrawing in excess of the optimal level. Sporadically Enforced Targets had an even higher average token withdrawal, 71.3, with 100% of groups on average having excess withdrawal. The percentages of groups withdrawing in excess of the optimal level are significantly different.

TABLE 4—AVERAGE GROUP TOKEN WITHDRAWAL.

	Average Group Token Withdrawal	Percentage Of Groups with Average Above Optimal
Threshold CPR with Complete Threshold Information	61.7	50
Threshold CPR with Incomplete Threshold Information	66.5	83.3
Threshold CPR with Sporadically Enforced Targets	71.3	100
All Groups	66.5	77.8

Using a Wilcoxon Rank Sum test, the average group levels of withdrawal were compared to one another as well as looking at the groups from each experimental treatment that exceeded the optimal level. There was a significant difference between the Complete Threshold Information and Incomplete Threshold Information at the 10% level (z = -1.674 p=0.09). At the 1% level (z = -2.483 p=0.0130), there was a significant difference between average withdrawal of those groups who played the Sporadically Enforced

Target experimental treatment and those who played under Complete Threshold Information. While no significant difference was seen in comparing the average withdrawal, there was a significant difference in the number of groups whose average withdrawal exceeded the optimal level. Comparing the groups exceeding the socially optimally level of extraction from Complete Threshold Information to the number of groups exceeding the socially optimal level of extraction from Sporadically Enforced Targets, using a rank sum test, results in a z-statistic of z = 2.769 and a p-value of 0.0056; there is a significant difference at the 1% level. There was also a significant difference in the number of groups withdrawing in excess of the socially optimal level when comparing Complete Threshold Information to Incomplete Threshold Information (z = 1.696 p = 0.0900). Finally, there was also a significant different at the 10% level (z = 1.813 0 = 0.0699) when comparing the number of groups that had excess withdrawal between the Incomplete Threshold Information and Sporadically Enforced Targets treatment. This matches with the hypothesis that Sporadically Enforced Targets would have a shorter common-pool lifespan that Complete Threshold Information or Incomplete Threshold Information, meaning they would have greater levels of withdrawal and withdrawal in excess of the optimal amount.

The CPR was overwhelmingly depleted in all three experimental treatments. Only three groups received the label of "sustainable." All other groups depleted the resource. While 22% of groups did have an average withdrawal which was at or below the optimal level, with the majority coming from the Complete Threshold Information treatment, these groups were not able to maintain this level of withdrawal. As seen in Figure 5 - Figure 7 showing the number of tokens remaining in the CPR, groups would start off withdrawing an optimal or close to optimal amount and then one or more group members would want more tokens, collapsing all group cooperation. When groups were cooperating, the level of tokens in the pool remained close to 1000. Eventually, the groups which were withdrawing close to the optimal level of withdrawal would deplete the CPR. The groups which cooperated for longer periods were able to keep the CPR close to 1000 tokens the longest. Some groups would over withdraw in initial rounds, decreasing the size of the common-pool. In this event, even if a group were to adopt the strategy of withdrawing 58 and 55 tokens in a later round, it would no longer be the strategy which would result in returning the CPR to full capacity. Many groups withdrew tokens in excess of the optimal 58-55 token solution, in favor of the Pareto inferior solution. Due to excess withdrawal, the CPR was depleted in all three experimental treatments with the exception of one sustainable group in each treatment.

- ***Result 4. The majority of groups, 77.8%, withdrew tokens in excess of the optimal strategy. Over-withdrawal resulted in 33 of 36 groups depleting the CPR.***

D. Pre-Threshold and Post-Threshold Behavior

Before crossing the threshold individuals were withdrawing tokens at levels significantly below their 25 token maximum allowances. This can be seen in Figure 11 in which the two periods prior to the threshold being crossed are examined. Two periods before the threshold was crossed the average amount of tokens withdrawn by an individual was 14.25. One period before the threshold was crossed the average withdrawal was 16.15 tokens. After the threshold was crossed and recharge to the common-pool ceased, individuals withdrew more tokens for their private fund. The number of individuals who were withdrawing their full allotted 25 tokens more than doubled and the average withdrawal increased to 21.6, 21.57, and 22.05 for the first, second and third period after the threshold was crossed, respectively. Once recharge was terminated by crossing the threshold, there no longer existed an incentive to slowly withdraw tokens from the CPR. Individuals entered into a race with their group members to deplete the resource. If one did not take their full 25 tokens then another player could withdraw the remaining tokens for their private fund (while remaining within their 25 token limit). Previously there was an incentive to leaving tokens in the common-pool, but without recharge that incentive is non-existent. If players do not put tokens into their private fund, another player will. Tokens will not remain in the common-pool.

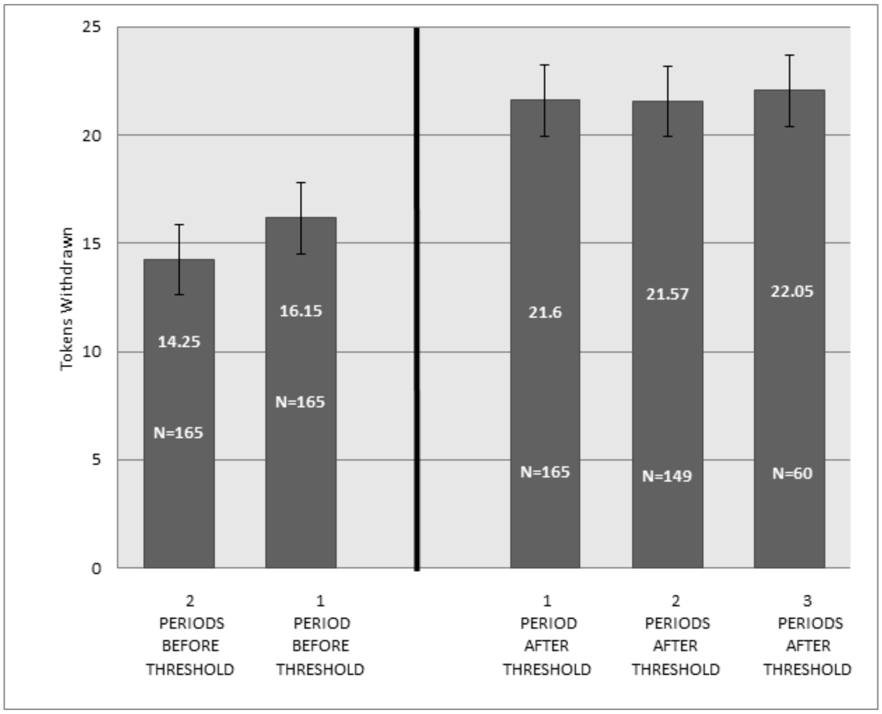

FIGURE 11.

Individual token withdrawal pre-threshold and post-threshold shows an increase in withdrawal once the threshold is crossed.

V. Conclusion and Policy Recommendations

A. Conclusion

CPRs can have a threshold for consequences. In order to delay resource users from crossing this threshold, policymakers set their own targets which they claim will be enforced. However, the policy maker's targets are repeatedly readjusted with no enforcement. In the laboratory, this process of Sporadically Enforced Targets resulted in a reduction of the CPR lifespan and decreased profits. Due to the constant readjustment, individuals were not able to rely on the information they were given. Without reliable information, individuals made decisions which shortened the common-pool life. However, when individuals weren't given any target information at all, they developed their own beliefs which acted as reliable information. Any reliable information, either given or from one's own beliefs, provided significant gains over Sporadically Enforced Targets both in terms of individual gains and the lifespan of the CPR.

While this paper is the first to examine threshold CPRs with uncertainty in an experimental setting, the findings built on previous literature. The shorter common-pool lifespan exhibited under Sporadically Enforced Targets resulting from a lack of enforcement and uncertainty of the punishment threshold is consistent with the unraveling of conditional cooperation in the absence of punishment (Gächter, 2007). Also consistent with the punishment literature (Fehr and Gächter, 2000; Nikiforakis and Normann, 2008; Ostrom et al., 1992; Wade, 1987), when punishments and policy targets were enforced they were an effective tool for reducing individual withdrawal from the CPR and increasing its longevity. In contrast, when left unenforced they increased resource use and decreased the resource lifespan.

Previous literature with uncertainty within CPRs focused on uncertainty in the resource size, finding that users withdrew greater amounts of the resource more rapidly (Budescu et al., 1995; Gustafsson et al., 1990). In contrast to the literature and the theoretical model of Diekert (2014), when uncertainty was placed on a punishment threshold, as in the Incomplete Threshold Information experimental treatment, there was no significant difference in individual token withdrawal or common-pool lifespan when compared against the treatment without uncertainty, the Complete Threshold Information experimental treatment. This is also in contrast to my initial hypothesis. The hypothesis that revealing the true threshold would result in the greatest CPR lifespan could not be supported. Providing individuals with any type of reliable information about the threshold in combination with information of the size of the common-pool resulted in the same benefits to the longevity of the lifespan of the CPR. Reliable threshold information included revealing the true threshold, enabling individuals to develop their own beliefs about the threshold, or enforcing policy targets/guesses of the threshold. When there was a greater degree of uncertainty, as with Sporadically Enforced Targets, individuals withdrew more tokens, more rapidly depleting the CPR when the threshold as well as the policy targets involved elements of uncertainty.

Threshold uncertainty in CPRs results in resource users consuming the resource in excess of the optimal level and depleting the resource more quickly than they would in cases of full information in regards to the threshold. Sporadically Enforced Targets, when non-credibly enforced, results in both a shorter common-pool lifespan and decreased earnings. Providing individuals with reliable information about the size of the CPR and the location of the threshold (given information or their own beliefs) will result in both economic gains and resource preservation.

B. Policy Recommendations

In order to effectively conserve a threshold CPR and maximize its lifespan, policymakers should make resource users aware that a threshold exists and of the size of the common-pool. While one might argue that making the resource users aware of the location of the threshold should be the recommended policy, that would not be advisable in a real world situation. My findings indicate that addition of true, reliable information beyond one's own beliefs had no significant gains in the lifespan of the CPR. Additionally, due to governmental present-biased preferences (Horowitz, 1996), announced targets and estimates of threshold locations cannot be permanently and irrevocably established. For this reason these estimates (targets) will often get readjusted, resulting in a situation in which a real world Complete Threshold Information case will morph into a situation much like the Sporadically Enforced Targets case. Since threshold CPRs under Sporadically Enforced Targets had a significantly shorter lifespan and produced smaller individual earning than when individuals were able to rely on their beliefs alone, I determined that if one cannot count on announced targets or policies to be credible, the best policy would be one in which individuals developed their own beliefs. My findings support the notion that governments and policymakers should be more firm with thresholds that they set, while also demonstrating that a threshold which is unenforced is more detrimental than no threshold at all.

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Experimental Instructions

A1. Threshold Common-Pool Resource Experiment with Complete Threshold Information Instructions

If you have any questions as we go through these instructions, please raise your hand and one of the monitors will come and answer your question.

In this game, you will have the opportunity to earn cash rewards. The amount that you earn will depend upon the independent decisions that you make and also upon the independent decisions that the others in your group make. You will receive a minimum of $5 for showing up and participating. You will be playing with tokens on the computer. Each token is worth $0.025 and your earnings are dependent on how many tokens you collect into your private fund. The more tokens you have at the end of the game, the more money you earn, so it is in your interest to accumulate tokens and increase your pay, while avoiding penalties that will cause you to lose tokens and decrease your pay.

Each of you has been randomly assigned to a group of 5 members. All members of your group are in this room. However, there is no communication or collaboration among the members of your group, and all decisions are made independently.

Each group will start with a shared, common pool of 1000 tokens. The roles of each of 5 players will rotate around the group each round, similar to changing the dealer in a game of cards. In each round there will be 4 group members who are withdrawing tokens. The 5th member will sit out of the round.

When you are in the role of a withdrawing player, each round provides the opportunity to collect tokens from the common pool and increase your private fund. After all members have completed the round, the common pool will get partially refilled or "recharged," by the computer, which will add more tokens back to the common pool total. The more tokens left in the common pool at the end of a round, the more additional tokens get added back to recharge and refill the pool. Similarly, the fewer tokens left in the common pool at the end of a round, the fewer additional tokens get added back to recharge and refill the pool. This is similar to earning interest or a reward based on the amount of tokens in the common pool. There is an opportunity to keep the common pool large which would allow more rounds of play to increase your private fund.

However, if the total number of tokens in the common pool gets too low - drops below 327 tokens - there will be negative consequences for all group members. This is similar to a requirement to maintain a minimum account balance in the common pool. If the common pool drops below the threshold of 327, for the rest of the game there will be no recharge - the pool will not be refilled after each round - and, in addition, each group member will lose $\frac{1}{3}$ of the tokens on hand in their private fund.

When you are one of the 4 withdrawing players, you individually decide how many tokens you would like to withdraw from the common pool to add to your private fund, knowing that the other players are doing the same. You will be shown the current number of tokens in the common pool and the maximum number of tokens which you can remove. You are allowed to take out from 0 up to 25 tokens each round. You will enter the desired number in the box on the computer screen and then click the "OK" button.

The other members of your group will also be making their own independent withdrawal decisions. The tokens which you remove from the common pool will get placed in your private fund and are not available to other members, and likewise, the tokens withdrawn by other members of the group are placed in their own individual private funds and are not available to you.

After all members have taken their desired tokens from the common pool, as long as the common pool remains above the 327 token threshold, the pool will get recharged. At the conclusion of the round, after all 4 players have chosen their amount of withdrawal, a screen will display the total number of tokens currently in the common pool and the number of tokens collected into your private fund.

If at the end of the round, the number of tokens in the common pool is too low and is below the threshold, all group members will be notified on the computer screen, they will all lose $\frac{1}{3}$ of their private fund tokens, and recharge of the common pool will cease. If the threshold has not been reached, play continues for the next round as before.

A new round will start with the jobs rotated, and a different player will sit out of the round. Then the 4 withdrawing members will make their independent decisions for withdrawal from the common pool, from 0 to 25 tokens. As before, the size of the pool and the total number of tokens in your private fund will be displayed. Play will continue until the common pool level is "broke" - so small that all withdrawing members cannot withdraw their maximum allotment.

All decisions will be kept anonymous. The number of tokens in your private fund at the end of the experiment will determine your earnings. Each token in your private fund will be converted to 2.5 cents.

Remember:

• 1 token = $0.025

• You will receive a show-up payment of $5

• You withdraw 0 to 25 tokens each period from the common pool that is available to all players

• When the total number of tokens in the common pool gets too low, below the 327 tokens:

• Recharge to the pool STOPS for the rest of the game

•All group members lose $\frac{1}{3}$ of their tokens

• The more tokens you have at the end of the game, the more money you earn, so it is in your interest to accumulate tokens and increase your pay, while avoiding penalties that will cause you to lose tokens and decrease your pay.

The tokens which you remove from the common pool will get placed in your private fund and are no longer available to other members, and likewise, the tokens withdrawn by other members of the group are placed in their own individual private funds and are no longer available to you.

A2. Threshold Common-Pool Resource Experiment with Incomplete Threshold Information Instructions

Instructions:

If you have any questions as we go through these instructions, please raise your hand and one of the monitors will come and answer your question.

In this game, you will have the opportunity to earn cash rewards. The amount that you earn will depend upon the independent decisions that you make and also upon the independent decisions that the others in your group make. You will receive a minimum of $5 for showing up and participating. Most people earn $15 on average. You will be playing with tokens on the computer. Each token is worth $0.025 and your earnings are dependent on how many tokens you collect into your private fund. The more tokens you have at the end of the game, the more money you earn, so it is in your interest to accumulate tokens and increase your pay, while avoiding penalties that will cause you to lose tokens and decrease your pay.

Each of you has been randomly assigned to a group of 5 members. All members of your group are in this room. However, there is no communication or collaboration among the members of your group, and all decisions are made independently.

Each group will start with a shared, common pool of 1000 tokens. The roles of each of 5 players will rotate around the group each round, similar to changing the dealer in a game of cards. In each round there will be 4 group members who are withdrawing tokens. The 5th member will play the role of a policy maker and will have a different task at the beginning of each round, just like the dealer has a different role in card games.

When you are in the role of a withdrawing player, each round provides the opportunity to collect tokens from the common pool and increase your private fund. After all members have completed the round, the common pool will get partially refilled or "recharged," by the computer, which will add more tokens back to the common pool total. The more tokens left in the common pool at the end of a round, the more additional tokens get added back to recharge and refill the pool. Similarly, the fewer tokens left in the common pool at the end of a round, the fewer additional tokens get added back to recharge and refill the pool. This is similar to earning interest or a reward based on the amount of tokens in the common pool. There is an opportunity to keep the common pool large which would allow more rounds of play to increase your private fund.

However, if the total number of tokens in the common pool gets too low - drops below a certain threshold - there will be negative consequences for all group members. This is similar to a requirement to maintain a minimum account balance in the common pool. If the common pool drops below the threshold, for the rest of the game there will be no recharge - the pool will not be refilled after each round - and, in addition, each group member will lose $\frac{1}{3}$ of the tokens on hand in their private fund. The game changing threshold amount is not revealed to the group members, until after the number of tokens in the common pool is less than the threshold.

At the beginning of each round, the policy maker will secretly make an official guess for the location of the threshold. This will be done on the computer, entering the number of tokens in the common pool believed to be the threshold where the negative consequences will go into effect. For example, if the policy maker enters "999" this means that (s)he believes that when the common pool drops below 999 tokens, recharge will stop and everyone will lose $\frac{1}{3}$ of their tokens. If the policy maker enters "3" this means that (s)he believes that when the common pool drops below 3 tokens, recharge will stop and everyone will lose $\frac{1}{3}$ of their tokens. Of course, the policy maker may not choose a threshold higher than the number of tokens currently in the pool. While each guess of the value of the threshold is stored in the computer and is linked to the policy maker, it is secret and not revealed to other members of the group.

When you are one of the 4 withdrawing players, you may guess for yourself, if you wish, where you think the threshold might be, and then individually decide how many tokens you would like to withdraw from the common pool to add to your private fund, knowing that the other players are doing the same. You will be shown the current number of tokens in the common pool and the maximum number of tokens which you can remove. You are allowed to take out from 0 up to 25 tokens each round. You will enter the desired number in the box on the computer screen and then click the “OK” button.

The other members of your group will also be making their own independent withdrawal decisions. The tokens which you remove from the common pool will get placed in your private fund and are not available to other members, and likewise, the tokens withdrawn by other members of the group are placed in their own individual private funds and are not available to you.

After all members have taken their desired tokens from the common pool, as long as the common pool remains above the actual threshold, the pool will get recharged. At the conclusion of the round, after all 4 players have chosen their amount of withdrawal and 5th player has made entered their secret guess of the threshold, a screen will display the total number of tokens currently in the common pool and the number of tokens collected into your private fund.

If at the end of the round, the number of tokens in the common pool is too low and is below the threshold, all group members will be notified on the computer screen, they will all lose $\frac{1}{3}$ of their private fund tokens, and recharge of the common pool will cease. If the threshold has not been reached, play continues for the next round as before.

A new round will start with the jobs rotated, and a different player in the role of policy maker, making a secret guess of the threshold. Then the 4 withdrawing members will make their independent decisions for withdrawal from the common pool, from 0 to 25 tokens. As before, the size of the pool and the total number of tokens in your private fund will be displayed. Play will continue until the common pool level is “broke” - so small that all withdrawing members cannot withdraw their maximum allotment.

All decisions will be kept anonymous. The number of tokens in your private fund at the end of the experiment will determine your earnings. Each token in your private fund will be converted to 2.5 cents.

Remember:

• 1 token = $0.025

• You will receive a show-up payment of $5

• You withdraw 0 to 25 tokens each period from the common pool that is available to all players

• Each round a rotating policy maker makes a secret official guess of the value of the threshold

• When the total number of tokens in the common pool gets too low, below the threshold:

• Recharge to the pool STOPS for the rest of the game

• All group members lose $\frac{1}{3}$ of their tokens

• The more tokens you have at the end of the game, the more money you earn, so it is in your interest to accumulate tokens and increase your pay, while avoiding penalties that will cause you to lose tokens and decrease your pay.

The tokens which you remove from the common pool will get placed in your private fund and are no longer available to other members, and likewise, the tokens withdrawn by other members of the group are placed in their own individual private funds and are no longer available to you.

A3. Threshold Common-Pool Resource Experiment with Sporadically Enforced Targets Instructions

Instructions:

If you have any questions as we go through these instructions, please raise your hand and one of the monitors will come and answer your question.

In this game, you will have the opportunity to earn cash rewards. The amount that you earn will depend upon the independent decisions that you make and also upon the independent decisions that the others in your group make. You will receive a minimum of $5 for showing up and participating. You will be playing with tokens on the computer. Each token is worth $0.025 and your earnings are dependent on how many tokens you collect into your private fund. The more tokens you have at the end of the game, the more money you earn, so it is in your interest to accumulate tokens and increase your pay, while avoiding penalties that will cause you to lose tokens and decrease your pay.

Each of you has been randomly assigned to a group of 5 members. All members of your group are in this room. However, there is no communication or collaboration among the members of your group, and all decisions are made independently.

Each group will start with a shared, common pool of 1000 tokens. The roles of each of 5 players will rotate around the group each round, similar to changing the dealer in a game of cards. In each round there will be 4 group members who are withdrawing tokens. The 5th member will play the role of a policy maker and will have a different task at the beginning of each round, just like the dealer has a different role in card games.

When you are in the role of a withdrawing player, each round provides the opportunity to collect tokens from the common pool and increase your private fund. After all members have completed the round, the common pool will get partially refilled or "recharged," by the computer, which will add more tokens back to the common pool total. The more tokens left in the common pool at the end of a round, the more additional tokens get added back to recharge and refill the pool. Similarly, the fewer tokens left in the common pool at the end of a round, the fewer additional tokens get added back to recharge and refill the pool. This is similar to earning interest or a reward based on the amount of tokens in the common pool. There is an opportunity to keep the common pool large which would allow more rounds of play to increase your private fund.

However, if the total number of tokens in the common pool gets too low - drops below a certain threshold - there will be negative consequences for all group members. This is similar to a requirement to maintain a minimum account balance in the common pool.

If the common pool drops below the threshold, for the rest of the game there will be no recharge - the pool will not be refilled after each round - and, in addition, each group member will lose $\frac{1}{3}$ of the tokens on hand in their private fund. The game changing threshold amount is not revealed to the group members, until after the number of tokens in the common pool is less than the threshold.

At the beginning of each round, the policy maker will secretly make an official guess for the location of the threshold. This will be done on the computer, entering the number of tokens in the common pool believed to be the threshold where the negative consequences will go into effect. For example, if the policy maker enters "999" this means that (s)he believes that when the common pool drops below 999 tokens, recharge will stop and everyone will lose $\frac{1}{3}$ of their tokens. If the policy maker enters "3" this means that (s)he believes that when the common pool drops below 3 tokens, recharge will stop and everyone will lose $\frac{1}{3}$ of their tokens. Of course, the policy maker may not choose a threshold higher than the number of tokens currently in the pool.

This guess will be announced to the rest of the group.

After seeing the policy maker's guess of the threshold, when you are one of the 4 withdrawing players, you may guess for yourself, if you wish, where you think the threshold might be, and then individually decide how many tokens you would like to withdraw from the common pool to add to your private fund, knowing that the other players are doing the same. You will be shown the current number of tokens in the common pool and the maximum number of tokens which you can remove. You are allowed to take out from 0 up to 25 tokens each round. You will enter the desired number in the box on the computer screen and then click the "OK" button.

The other members of your group will also be making their own independent withdrawal decisions. The tokens which you remove from the common pool will get placed in your private fund and are not available to other members, and likewise, the tokens withdrawn by other members of the group are placed in their own individual private funds and are not available to you.

After all members have taken their desired tokens from the common pool, as long as the common pool remains above the actual threshold, the pool will get recharged. The policy maker will then see the current number of tokens in the pool after withdrawal and recharge. They will then have the option to enforce their guess and punish the other group members for getting too close to where they believe the threshold is located, for taking out too many tokens. If they decide to punish, in exchange for 100 personal tokens paid back to the common pool, 50 tokens are removed from the private funds of the 4 withdrawing players. These tokens disappear.

At the conclusion of the round, after all 4 players have chosen their amount of withdrawal and policy maker has made entered their punishment decision, a screen will display the total number of tokens currently in the common pool and the number of tokens collected into your private fund.

After all 4 players have chosen their amount of withdrawal and the policy maker has made enforcement decision, a screen will display the total number of token in the common pool and the number of tokens in your private fund. If the policy maker should choose to punish the other group members you will be notified.

A new round will start with the jobs rotated, and a different player in the role of policy maker, making an announced guess of the threshold. Then the 4 withdrawing members will make their independent decisions for withdrawal from the common pool, from 0 to 25 tokens. This is followed by the policy maker making their enforcement decision. As before, the size of the pool and the total number of tokens in your private fund will be displayed. Play will continue until the common pool level is "broke" - so small that all withdrawing members cannot withdraw their maximum allotment.

You will be notified if the policy maker chose to punish. You will also be notified when the number of tokens in the pool has reached the true threshold, the number of tokens is too low and negative consequences have taken place.

All decisions will be kept anonymous. The number of tokens in your private fund at the end of the experiment will determine your earnings. Each token in your private fund will be converted to 2.5 cents.

Bankruptcy: If you should have negative tokens at any point, you can invest your $5 show-up payment into the game to cover your loss.

Remember:

- 1 token = $0.025
- You will receive a show-up payment of $5
- You withdraw 0 to 25 tokens each period from the common pool that is available to all players
- Each round a rotating policy maker makes an announced guess of the value of the threshold
- The policy maker can enforce the guess of the threshold:
    - Paying 100 tokens to the common pool
    - Taking away 50 tokens from all other players
- When the total number of tokens in the common pool gets too low, below the threshold:
    - Recharge to the pool STOPS for the rest of the game
    - All group members lose $\frac{1}{3}$ of their tokens
- The more tokens you have at the end of the game, the more money you earn, so it is in your interest to accumulate tokens and increase your pay, while avoiding penalties that will cause you to lose tokens and decrease your pay.

The tokens which you remove from the common pool will get placed in your private fund and are no longer available to other members, and likewise, the tokens withdrawn by other members of the group are placed in their own individual private funds and are no longer available to you.