Domination and mutualism: Consumption and conservation of resources in the lab.

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Abstract

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I develop a game theoretic model in which a resource pool has a common pool and public good aspect in its usage, such as hunting (consumption) and conservation of wildlife. I then implement a laboratory experiment to evaluate how spillovers between the two related resource accounts affect consumption and conservation behaviors. The Nash prediction suggests payoff maximizing agents will increase spending on both consumption and conservation until both are equivalent when resource spillovers are present. Results from laboratory experiments are consistent with this hypothesis. As a policy intervention, I introduce and then later revoke a common pool licensing policy based on U.S. hunting and fishing licensing. Under the same theoretical framework, removing a common pool licensing policy would increase welfare for all resource stakeholders. Contrary to this, experimental evidence indicates no overall change in welfare. After removing the restrictive licensing policy the increase in the quantity of agents consuming from the commons is offset by a per-subject reduction in the amount of common pool investment.

Keywords: Common pool resource, public good, natural resource, experimental economics.

1 Introduction

Natural resource management agencies must balance consumption and conservation. Resource managers often classify differing resource preferences as either *domination-oriented* consumption (hunting, fishing, resource extraction) or *mutualist-oriented* consumption (wildlife spotting, education, resource conservation).[1]

Consider, for instance, the presence of gray wolves (*Canis lupus*) in Yellowstone National Park and the surrounding lands. Historically the grey wolf had significant value as a hunting resource for their pelts. [2] At the same time, the presence and conservation of wolves has value as a public good to resource stakeholders in the environmental quality of Yellowstone and the land surrounding it. Gray wolves help control the population of herbivorous mammals, like elk, that eat young saplings, which diminishes forest growth. Gray wolves also benefit the environment by controlling the populations of coyote and other predatory species that can be more destructive to wildlife when their populations go unmanaged. By 1926 the gray wolf population in the areas of Yellowstone National Park had been extirpated by years of overhunting.

Following the wolf population decline below the sustainable population level, the local elk population boomed, drastically harmed the forest growth of Yellowstone and reduced the value of the national park as a public good. After the reintroduction of gray wolves to Yellowstone in the 1990s, the once overgrazing elk population returned to a sustainable level again. The reintroduction of the gray wolf also had the added benefit of improving the biodiversity of the local ecosystem. Game that once had been driven from Yellowstone by the overgrazing elk returned to the area, such as beavers and grizzly bears (Ripple, 2013). The regions surrounding Yellowstone perfectly illustrate this multidimensional idea of a resource pool, one that has value through extraction and value through preservation. Moreover, the history of hunting and conservation in the Yellowstone area represents significant spillovers between these methods of consumption or resource accounts.

In the following model and laboratory experiment, I model a combined game consisting of separate resource accounts, one being a common pool resource (CPR) extraction game and the other being a linear public good (PG), and impose the account spillovers motivated by the type of spillovers illustrated in the history pf Yellowstone above. The account spillovers are employed to understand how the potential for resource collapse can impact investment

[1]These classifications are derived from an L. Charles Hilton Jr. Center presentation, provided by Dr. Chelsea Crandall of the Florida Department of Fish and Wildlife Conservation Commission's Social Science research group, but are also provided in Manfredo, Teel, Dietsch, et al. (2020)

[2]It should be noted that Yellowstone grey wolf hunts were also motivated by local ranchers protecting their livestock, and federal sanctioning of the wolf's extermination in the early 20^{th} century.

decisions in both uses of nature. Theoretical and empirical results suggest that these resource account spillovers exasperate the social dilemmas from the common pool and public good accounts. In response, I also employ a common pool extraction licensing policy modeled after Florida fish and wildlife policies that provide capped extraction licenses via lottery to a select few resource stakeholders. Theory predicts that the common pool's social dilemma is mitigated. However, the public good social dilemma is worsened. Because some resource stakeholders are barred from participating in the extraction process, they do not receive the additional conservation benefits of the public good that stem from the account spillovers, thus eliminating a significant incentive to provide conservation efforts.

In my model, resource stakeholders make investment decisions in two resource accounts, a production account (common pool) and a public account (linear public good). Resource stakeholders receive an endowment that they use to invest into either account or save in a private account. For a non-linear common pool production function, a baseline game in which there are no spillovers between resource accounts predicts that profit-maximizing agents will over-extract from the common pool account and leave the public account utilized. The Nash Equilibrium has the characteristics of those from Ostrom, Gardner, and Walker 1992; with the addition of a low-yield public good that goes unused ex-ante. When introducing threshold externalities that harm conservation and benefit extraction, the Nash prediction suggests that the spillovers induce a balanced investment in both the common pool and public good properties of the environment. Seeing as the resource stakeholders may be both consumers and conservationists, this Nash Equilibrium also has the added benefit of explaining how we often see in the field that many consumers of the commons (hunters, fishers, etc.) are likewise often conservationists.

While there is already an extensive experimental economics literature for both common pool resources and public goods, the value this model provides is the recognition that resource pools provide both extraction and conservation based goods whose productions conflicts with one another. Moreover, the externality spillovers between my two modeled resource accounts constitute a novel contribution to both the environmental and experimental economics literature. These spillovers capture the decline from over extraction and benefits of conservation that are observed in the field, such as in the discussed case of the Yellowstone Gray Wolf.

Despite the many scenarios in the natural resource field for which we can model resource use as a multidimensional problem of domination and mutualism there has been little exploration of this topic. This paper contributes to the natural resource and experimental literature by allowing a resource pool to have both value in depletion and conservation. Moreover, the model and experiment allow for policy and naturally occurring externalities, to be explored in this economic setting. My model introduces a combined resource pool game in which there is a common pool investment (consumption) aspect and a public good donation (conservation) aspect, that extends problems of resource management across two separate, but connected dimensions. I employ externalities modeled off of resource decay and positive trophic spillovers to understand how negative and positive shocks to these multidimensional resource pools impact preferences towards resource consumption and conservation.

To test the hypotheses generated by this combined model and the resource spillovers, I parameterize the game and spillover treatments for a laboratory setting, varying the presence of spillovers and a common pool licensing policy across intervals of games played in groups. This presence of the spillover treatment effect helps illustrate how the benefits of conservation are most often realized by the appropriators of a resource. The license policy treatment, likewise, evaluates the efficiency of many related hunting and fishing policies around the US.

This line of research is most closely related to the experimental literature on common pool resource constituent games, in which resource stakeholders make investment decisions to commonly produce a rivalrous resource (Walker and Gardner 1992; Ostrom, Walker, Gardner 1992; Cardenas, Stranlund, Willis 2000). While game theoretic predictions of equilibria suggest frequent over use of the pooled resource in this literature, it is frequently the case that experimental evidence finds little over-consumption, or even evolving institutions to help mitigate resource deterioration.

In modeling the proposed anecdotal natural environment in the lab, this research also borrows heavily from the public goods literature, namely Isaac and Walker, 1988; Isaac, Walker, and Williams (1994); Isaac, Norton, and Pevnitskaya, 2018; and Cardenas and Carpenter, (2005). In Isaac, Norton, and Pevnitskaya (2018), the authors construct a public account that serves as a public good for some, and a ”public bad” for others. While the primary motivation in this article is on how a censoring mechanism on investment alters public account balances, the concept of common investment decisions inducing negative public account balances for resource stakeholders serves as the theoretical motivation behind negative externalities between a combined common pool resource and linear public goods game.

The classifications of domination and mutualist-oriented preferences, as illustrated in Manfredo, Teel, Dietsch, et al. (2020), are important for policy makers as they illustrate the demand for differing uses of the environment. Domination-oriented users are those with preferences towards private ownership of the environment, predominantly those that express a preference towards rule of capture in extracting resources. Mutualist-oriented users, however, have preferences for the environment to have its own right to exist. Mutualism is exhibited through preferences towards conservation and sustainability of the environment. In adopting the concepts of domination and mutualism into my research design, my model addresses the extent to which environmental externalities shape stakeholder preferences over these resource uses.

2 Consumption and Conservation Game

The proposed game has a group of n agents make investment decisions in three accounts, two of which are tied to a shared resource pool. Agents are given an endowment of $e > 0$ tokens that they may invest in a production account (common pool resource) and a public account (linear public good). For any tokens not invested in either of the two resource accounts, they are automatically saved in a private account with a fixed rate of return $w > 0$. This environment mimics several aspects of resource pools on public land, such as fish and wildlife in state or national parks. For example, there are several mixtures of investing in this resource that are viable. Decision-makers may choose to strictly invest in the production account, and extract (hunt) from the resource pool. They may also choose to strictly invest in the conservation of this resource by donating to a public good that benefits all resource stakeholders. Any mixture of these two behaviors is also possible.

The production account follows the typical constituent game published in Ostrom, Walker, Gardner (1992). The production account is a shared resource account in which decision-makers may invest x_i tokens in the production of the resource pool, and split the bounty according to their investment's weight against total investment. Specifically, using the Ostrom, Gardner, Walker (1992) parameterization, the individual return on the production account is equal to

$$\frac{x_i}{\sum x_j} F(\sum x_j) = \frac{x_i}{\sum x_j}[a \sum x_j - b(\sum x_j)^2] \tag{1}$$

where $a > 0$ and

$$F'(2nw) = a - 2bnw < 0 \tag{2}$$

This specification for a quadratic production function has the symmetric property that doubling the socially optimal group investment yields no net return.

For the public account, this account follows the standard design for a linear public good where donations to the good are vertically additive. Namely, for any donation d_i to the public account, the return on the account is given by

$$G(\sum d_j) = c \sum d_j \tag{3}$$

where $c > 0$. A linear public good illustrates the vertically additive nature of natural resources to consumers. Unlike most competitive rivalrous markets, the value of nature is not determined by the individual with the highest value or willingness to pay, but rather the sum of values all stakeholders have over it.

Combining this information, we have a combined individual payoff on investment decisions given by:

$$\pi_i = w(e - x_i - d_i) + \frac{x_i}{\sum x_j} F(\sum x_j) + G(\sum d_j) \tag{4}$$

Assume furthermore that $a > w > c$. This means that on the increasing domain of the quadratic production account function, the marginal return on tokens is greater than the outside alternative of saving those tokens in the private account, which also yields a higher marginal return than investing in the public account that benefits the whole group. The marginal returns over all three accounts are calibrated in such a way to capture the essence of how resource stakeholders engage with the environment. Stakeholders in the field would not hunt if an outside alternative was always more beneficial. Additionally conservation has little individual return, but greater benefits to the group as a whole.

The Nash Equilibrium for the game, as specified, is identical to that of the baseline constituent game found in Ostrom, Walker, Gardner (1992). Namely the symmetric Nash Equilibrium is

$$\sum x^* = \frac{n}{n+1}(\frac{a-w}{b}) \tag{5}$$

and

$$\sum d^* = 0 \tag{6}$$

This Nash Equilibrium exists on the decreasing marginal return side of the quadratic production function. Meaning, we would expect profit maximizing agents to marginally over-extract the resource to the point where any additional token of investment will decrease the total value of production, while decreasing investment by one token would increase the total value. Consequentially, in this environment without resource account spillovers we would also expect no investment in the public account for the linear public good. Therefore, any token not spent on the production account would be automatically saved in the decision-makers' own private accounts.

While the resource stakeholders are modeled to maximize their return on investments across all three accounts, a social planner would instead maximize the group's total return from the three accounts. The social planner's problem is defined as:

$$max_{(\sum x, \sum d)} \Pi(\sum x, \sum d) = nwe - w\sum x - w\sum d + F(\sum x) + G(\sum d) \tag{7}$$

Similar to the competitive symmetric equilibrium, the social optimum that is derived from this social planner's problem draws from both the common pool literature and public good literature. The social optimum produced from the planner's problem is given by:

$$\sum x^{so} = \frac{a-w}{2b} \tag{8}$$

and

$$\sum d^{so} = ne - \sum x^{so} \tag{9}$$

This result illustrates that in order to maximize the sum of the stakeholder's returns on investing in the three resource accounts, they first approach the socially optimal investment in the common pool resource account, and invest whatever else remains of their endowment into the public good account. Conditions for the existence of this social optimum are provided in Appendix C. The key result of the symmetric Nash Equilibrium and the socially optimal investments is that even with two group oriented production methods of a resource pool, there still exists a social dilemma from the common pool and a social dilemma from the public good. These calculations suggest $\sum x^{so} < \sum x^{*}$ and $\sum d^{so} > \sum d^{*}$, i.e. the common pool is predicted to be over invested in relative to the socially optimal outcome, and the public good is predicted to be under invested in.

Environments also often have spillovers between productive and public aspects. Returning to the previous anecdote of gray wolves around Yellowstone National Park, in the early 20^{th} century, wolves were hunted to perceived extinction in years of publicly organized hunts. The over-hunting of wolves led to a massive boom in elk populations that decimated forest growth with over-grazing. After a public effort of reintroducing wolves in the mid to late 1990's, these effects began to balance out, and both recreational hunters and conservationists benefited from the new biodiversity.

In the previous example, there are two specific spillovers between resource accounts. There is a negative externality from the common pool, over-hunting harming public value, and conservation benefiting the common pool, wildlife diversity benefiting recreational game hunters. To implement environmental externalities in my game theoretic model, I introduce two account spillovers defined by the thresholds τ_c and τ_p for common pool extraction and public good donations respectively. When the investment into the common pool exceeds the threshold τ_c, the balance on the public account diminishes. Similarly, when the balance in the public account meets or passes the threshold τ_p, the marginal return on the production account increases. Mathematically, the externalities are defined as:

1. Common Pool Externality: If $\sum x_j \geq \tau_c$, then $\sum d_j$ decreases by $(\sum x_j - \tau_c)$ tokens.

2. Public Good Externality: If $\sum d_j \geq \tau_p$, then the production account return becomes

$F_H(\sum x_j) = [a_H \sum x_j - b_H(\sum x_j)^2]$, where $a_H > a$ and $b_H < b$.

For the purpose of the model's simplicity, I impose the constraint that $\tau_c = \tau_p = \tau$, i.e. the externality thresholds are a uniform value for both the common pool and public good aspects of this resource environment.[3] Furthermore, I set $\tau = \sum x^{MSY}$, or the level of investment that correlates to the common pool's maximum sustainable yield. I make the latter assumption as a calibration from the field. The negative shocks to the quality of Yellowstone first occurred when the wolf population dropped below its sustainable level. Having the maximum sustainable yield be equivalent to an externality threshold thus has occurred in the field. Therefore, the interpretation of the maximum sustainable yield in this model is twofold. First, inline with the past common pool literature, it represents the point for which further investment in common pool production has a negative marginal return. Secondly, with my resource account spillovers, it represents the point for which over investment in common pool production results in a "public bad" for all resource stakeholders.

An important detail of the account spillovers to take note of is that they can interact by the way they are defined. For example, suppose $\sum x_j > \tau$ and the common pool externality is levied on the resource stakeholders. This externality decreases the balance of the public account. In the absence of public account donations, this would make the public account negative and make the public good into a "public bad". Because of the way the public good externality works, if the common pool externality is in effect, it will also take proportionally more donations to have the public good externality levied. For every token over invested in the production account (beyond τ), the public account balance will decrease by one token, meaning that it will take an additional token in order to reach the public account externality threshold. This scenario has the benefit of mimicking how over-hunting also means that conservation requires more effort in the field.

By design, the public good externality constitutes a public good of itself, albeit a threshold public good as opposed to the linear public good that is directly invested in. As this is the case, there are two feasible Nash Equilibria in the presence of resource account spillovers. The symmetric Nash Equilibrium for the baseline game provided in equations (5) and (6) persists, even with the presence of resource account spillovers. However, there is a second equilibrium that is added if the agents' endowments are sufficiently large, i.e. $n * e \geq 2\tau$, and agents are able to coordinate on sufficiently investing towards the linear public good. If such is the case, then there is a Nash Equilibrium in which both the production account is over-invested and the public account is sufficiently invested. We have that

$$\sum x_j^* = \frac{n}{n+1}\left(\frac{a_H - w}{b_H}\right) \tag{10}$$

[3]See Appendix C for discussion on the general model's comparative statics when $\tau_c \neq \tau_p$.

$$\sum d_j^* = \sum x_j^* \tag{11}$$

Because the resource spillovers share a common threshold, the only way in which conservation can yield the positive spillover is if conservation efforts match the level of extraction. For every token over invested in the common pool beyond the threshold, another token must be invested to the public good in order to meet the spillover threshold.

Figures 1 and 2 provide a graphical representation of the production functions for the two resource pool accounts and the private account. Figure 1 represents the baseline game without the spillovers between resource accounts. In this model, the only payment defining functions are represented by the production function for the common pool resource ("production account"), the public good production ("public account"), and total savings in the agents' private accounts. The illustrated CPR production function represents the type of quadratic production function that has been parameterized earlier in this section. Figure 2 however, illustrates the productive output for a group of decision makers in this resource environment, when there are spillovers between the CPR and public good. As illustrated, when the public good threshold is met, the productive capacity of the common pool resource becomes much higher, while over-investment in the common pool resource beyond the threshold will result in a deductions in the balance on the public good. This visually illustrates how the proposed externalities encapsulates how conservation improves productivity in the common pool, and how over-extraction reduces the benefits of conservation.

The social optimum level of investment into either resource account follows an expression similar to those found in the game without resource spillovers. For the game with spillovers, the socially optimal level investment in both accounts is given by:

$$\sum x^{so} = \frac{a_H - w}{2b_H} \tag{12}$$

$$\sum d^{so} = ne - \sum x^{so} \tag{13}$$

The key difference between this social optimum and that derived from the game without spillovers, is that due to the improvement in productivity resulting from the public good's positive spillover, the socially optimal level of investment in the CPR lies on the more productive curve. This results in more investment in the CPR relative to the game without spillovers and less investment in public good, but a far larger amount of return for the group as a whole with the spillovers in effect.

Because there are two symmetric Nash Equilibria in the game with spillovers, this introduces a coordination problem between the resource stakeholders on their preferred level of public good provision. If the decision-makers can coordinate on sufficient investment in the public good, then their group will approach the payoff dominant symmetric Nash Equilibrium in which they balance their investment equally across the CPR and public good. This however requires that the group is efficiently able to coordinate their public good investment. If any one agent is anticipated to defect and free ride on public good investment, the payoff dominant symmetric Nash Equilibrium will be unattainable. This coordination problem has the potential of exacerbating the social dilemmas stemming from the CPR and public good accounts, as unanticipated free-riding in the game with spillovers would lead to agents making decisions as if they were on the more productive CPR production function, but due to unanticipated free-riding, they remain on the less productive curve with a greater level of investment than they would have if the free riding were anticipated. With anticipated free riding, the simple decision is to coordinate on the symmetric Nash Equilibrium that the game with spillovers shares with the baseline game, where there is no investment whatsoever in the public good.

3 "Optimal" Licensing of the Commons

Consider the combined CPR and PG game with spillovers again, however now suppose that a central planner wishes to minimize the social dilemmas of this problem by instituting CPR investment licenses by lottery. Such a policy would closely resemble how most U.S. states determine hunting and fishing licenses for wildlife susceptible to over extraction. A direct example of this is represented by Florida's "Limited Entry/Quota Permits." Applications for permits are assigned a number and permit allocation is determined by a lottery after the application windows closes each year. Permits often allow for hunting animals like alligators and antler-less dear, that may be susceptible to over hunting in the absence of licenses or have highly varied populations in general.

In addition to quotas on resource extraction, several of the capped permits in Florida's fishing and wildlife policy encompass restrictions on "methods of extraction." For example, some of permits place restrictions on muzzle loading firearms used in hunting, bow hunting, and airboat usage. Hunting and fishing methods and the restrictions placed on them represent common models of common pool resources in that investment in the production of a common pool resource is typically indicative of investment in the methods or effort used in the production of the resource (Lueck, 2018).

For a CPR investment licensing policy to be optimal from the perspective of reducing the social dilemma in CPR extraction, it must reduce the number of resource stakeholders actively extracting the resource to a point where the competitive equilibrium is equivalent to the social optimum. In the field, demanding policy to follow this qualification is a costly endeavor, as it would require the regulatory agency to know the productivity of all hunters engaging with the resource. Instead what we frequently see regulatory agencies do is to instead reduce the number of resource users to a small group, and cap their total investment/extraction at the maximum sustainable yield. While not the first-best policy, the clear advantage of a consumption license capping extraction at the maximum sustainable yield almost entirely avoids costs of measuring output. While such a policy does not guarantee the elimination of the CPR social dilemma, as $\sum x^{SO} \leq \sum x^{MSY}$, the cap would place an upper bound on the competitive equilibrium between the resource stakeholders left with licenses. For those that are allocated a capped CPR investment license, this would translate to

$$\sum x^{SO} \leq \sum x_L^* \leq \sum x^{MSY}$$

meaning that the symmetric competitive equilibrium for those obtaining CPR licenses with capped investment will always be bound above by the level of investment correlated to the maximum sustainable yield, and bound below by the socially optimal level of investment.

Parameterizing the the CPR licensing-cap lottery into the combined CPR and PG game is a simple matter.[4] For the same combined game with spillovers, I assume the policy is designed such that half the stakeholders are assigned a CPR investment cap license. For the CPR aspect of the game, this effectively reduces the number of active participants to $\frac{n}{2}$, however for all other resource investment decisions pertaining to the conservation oriented public good and the resource stakeholders' private accounts, the actual group size is still all n-decision makers. This means that only $\frac{n}{2}$ agents receive an investment license with an investment cap set at the MSY for the common pool, and can therefore invest in common pool production. All n agents, whether they hold an investment license or not, may freely invest towards the public good and/or save any portion of their endowment for themselves in the private account.

Reducing CPR access does introduce a "fairness" problem among the group of resource stakeholders. Although the negative spillover from the CPR will never occur with the investment cap set at the MSY (which is the externality threshold for the model) it also means that only those with a CPR license experience the benefits of the public good's externality, should public good investment be large enough. To translate this issue back to the field from my model, this problem presents itself in hunting and fishing policy as hunters and fishers primarily experience the benefits from spillovers of conservation effort. While all resource stakeholders naturally benefit from investment in a linear public good, within the construction of this model only those engaging in CPR investment experience the positive

[4] A similar "limited access" policy for CPR games of the same parameterization can be found in Walker, Gardner, Ostrom (1990).

spillover from the public good. From conservation effort we obtain improved biodiversity and environmental quality, and those that often benefit the most from such trophic spillovers are those that extract (hunt) the animals from the environment. Those excluded from CPR access (those without a license) may find it unfair that, should they invest in the public good (conservation), that they do not experience the heightened CPR productivity.

While "fairness" is a concept more applicable to a behavioral model and experimental evidence (to be discussed in Section 5) there is something concrete to be said about social dilemmas when facing the proposed policy, according to this model. As a reminder, the parameterization of this model is such that the return on the private account savings is greater than the marginal per capita return on the public good ($c < w$). Since those agents who are not allocated a CPR investment license no longer reap the spillover benefits of PG investment, the symmetric Nash Equilbrium for them reduces to

$$\sum x^*_{NL} = 0 \tag{14}$$

as they cannot invest in the CPR without a license, and

$$\sum d^*_{NL} = 0 \tag{15}$$

as saving the entirety of their endowment yields them each individually the highest marginal return. For the half of the agents that obtain a capped CPR investment license, their symmetric Nash Equilibrium for the combined game with spillovers becomes

$$\sum x^*_L = \left(\frac{\frac{n}{2}}{\frac{n}{2}+1}\right)\frac{a-w}{b} \tag{16}$$

as the licensing policy effectively reduces the group size of CPR users, and

$$\sum d^*_L = 0 \tag{17}$$

assuming that endowments and group size are such that the positive PG spillover is unobtainable when CPR users are reduced by half.

The model therefore suggests that the social dilemma stemming from CPR over-investment is significantly reduced, as

$$\sum x^{SO} \leq \sum x^*_L \leq \sum x^{MSY}$$

. The proposed license-cap lottery policy does however introduce a worsened social dilemma stemming from the public good (conservation) aspect. The problem is fundamentally one of property rights. Because some stakeholders have a now weaker incentive to invest towards the public good. The socially optimal level of investment in the CPR and PG do not change in the face of this policy from the calculations provided for the game with spillovers in the previous section (i.e. the license lottery policy does not change the social optimum). For the game with spillovers and without the policy, we have that there is still a significant amount of investment in the public good, albeit still less than the social optimum, predicted by the symmetric competitive equilibrium. With the policy now, however, there is a weaker incentive to invest in the public good, and therefore it goes entirely uninvested at the competitive equilibrium. Such a policy would only be beneficial if and only if the reduction of the common pool social dilemma is greater than or equal to the increase in the public good social dilemma. This will never be the case however as it would require:

$$\sum x_L^* > 2 \sum x^*$$

i.e. it would require the new symmetric Nash Equilibrium under the licensing policy to be more than twice the symmetric equilibrium quantity of investment without the licenses. This is never true, as the licenses reduce the group size that may invest in the common pool resource which, all else equal, will always reduce the symmetric equilibrium investment level.

In summary, an investment capped license lottery policy would indeed reduce the issues stemming from the CPR social dilemma for the combined game with spillovers, however this improvement will always be dwarfed by a worsened public good social dilemma, ex ante. Although this result is specific to the modeled policy, it can be generalized to show the net gains of some a policy are always less than or equal to zero.[5] This means that there is no such optimal policy for the combined CPR and PG game with spillovers that would bar access of stakeholders to common pool investment.

4 Experimental Methodology & Hypotheses

The constructed game theoretic model provides hypotheses that can be sorted into answers to one of two questions.

1. How do spillovers between consumption and conservation (CPR and PG) affect investment decisions between the two resource accounts?

2. In the presence of social dilemmas, is licensing the commons effective at promoting sustainability without harming welfare?

[5]This proof is given in Appendix C.

The above questions provide the basis for the treatment design in my laboratory testing of the proposed model. The baseline game in the lab is structured to represent the baseline combined CPR and PG game without spillovers or licensing policy. To answer the first question, I observe investment decisions when resource account spillovers between a CPR and PG, as defined in Section 2, are implemented as a within-subjects treatment. To address the second question, I use the constructed laboratory experiment that simulates the game with spillovers, and vary the modeled CPR investment licensing policy as a within-subjects treatment.

Parameterizations for the game theoretic environment are provided in Table 1. Game environment was parameterized such that the group size was four subjects. All earnings that subjects could earn through the experiment were denoted in "Experimental Currency Units" (ECUs), where ECUs were converted into real money payments at the end of the experiment at the rate of $100ECUs = \$1.00$ for the spillover treatment sessions and $180ECUs = \$1.00$ for the licensing policy treatment sessions.[6] All other parameterizations of the game environment for the experiment, follow the assumptions in designing the model discussed in Section 2.

This experiment was programmed and tested over zTree (Fischbacher, 2007) at Florida State University's XS/FS experimental computer lab. Subjects were recruited over the XS/FS groups recruitment list of undergraduate experimental participants. This list draws from a pool of undergraduate students that have chosen to participate in the XS/FS group's laboratory research.

Images of the computer interface subjects interacted with are provided by Figures 3 and 4. In the experiment, and as can be seen in the images of the user interface, subjects were randomly sorted into groups of four. Each group was informed that they would play a sequence of 15 games and that they would remain in the same group for each game. Each game was explained to be independent from the previous game played, meaning that none of the information or decisions from the previous game would affect the interface in front of them during the current game or any later game. Subjects were also informed that their groups were independent from one another. So, any decision or outcome faced by **Group 1** in any period, would not affect **Group 2** or any other group, and vice versa. All subjects were provided with an endowment of 11 tokens in each round. They were informed that they may invest any amount of those tokens into any of three accounts; a production account (CPR), a public account (linear PG), or a private account. The returns on investing in the

[6]The adjusted pay scale for the license policy treatment sessions was undertaken as having the possibility of positive account spillovers in each round played would, ex ante, double payoffs between the two session types in the absence of a scale adjustment.

three accounts were provided to them in the instruction handout at the beginning of the experiment.

The production account was explained to subjects as an account where their group could invest to produce a pile of ECUs, and their individual return on that production would be distributed by how many tokens they individually invested in that account, proportional to the rest of the group's investment. The payoff function on the production account was provided both as a function and in table form to the subjects. The precise details of this function is provided in Table 1, and the payoff table on the production account can be found in the sample instructions provided in Appendix D. The public account, as the subjects were informed, was an account where their investment produced an ECU return for the entire group uniformly. Every token invested in the public account would produce 2 ECUs for each member of their group. The private account was described as an account where they could invest their tokens and earn a guaranteed four ECUs for each token invested.

Subjects were paid based on their decisions in each of the 15 games played for the session. Between each game, the ECUs earned from each account were visible on a "payoff screen" privately to each subject. Additionally, on this payoff screen, subjects could see how many total tokens from their group were invested in either the production and public accounts. This was done in order to improve efficient group coordination on investment decisions. In the absence of group level investment information between rounds and not seeing their own ECU earnings, the experimental design would run the risk of added noise in subject responses as they would have no context during the experiment for their earnings.

For some of the games played within a session, subjects experienced the baseline game without any spillovers between the resource accounts. For the remaining games of the 15 game sequence, subjects were told that their investments in the production account could affect the outcomes of the public account, and vice versa. The spillover from the production account was described to the subjects that any token invested in the production account beyond the threshold of 14 would lead to a one-token reduction in the public account's balance. As for the public account, the subjects were told that a balance of at least 14 tokens in the public account would cause the production account to become "more productive." The more productive return on the production account was given by a new function and a new table at the end of the instructions. In each laboratory session, the subjects were walked through how this new production function on the production account was more "productive" than if the public account threshold were not met. This illustrated to the subjects by choosing a cell on the first table to see the payoff without the spillover, and seeing how the same corresponding cell on the new payoff table would always have a return greater than or equal to those found in corresponding cells of the last table.

To evaluate the effects of the resource account spillovers on CPR and PG investment, I ran two treatment sequences. The first sequence had subjects play the baseline game for the first five games, the game with spillovers for games six through ten, and again the baseline game without spillovers for the final five games. Using this NS/S/NS design, henceforth to be referred to as "NS/S/NS", I can evaluate the within subjects treatment effect of the spillovers. For the second set of sessions ran in the XS/FS research lab, I chose a sequence where subjects would play the game with spillovers for the first and last five games, and the middle block of five games was played as the baseline without spillovers between resource accounts. Including the "S/NS/S", or S/NS/S ordering allows me to see if there are specific order effects between starting with and without spillovers. Moreover the inverted sequence design allows testing the spillover treatment effect between subjects, as each session sequence played a different block of five games (baseline or spillover) at any given period of the experiment.

For evaluating the investment cap license policy in this experimental environment, a new sequence of sessions was run with the modeled CPR license lottery system used as an experimental treatment. A new sequential strategy was followed for the policy treatment sessions. Each group of subjects played a sequence of 20 games of the modeled CPR and PG resource environment with externalities. For the policy treatment group of sessions, subjects played games in blocks of ten, where subjects would play the first 10 games with the licensing policy and the final 10 without.

For the first 10 games of the license treatment, subjects were told that, in each group, two out of the four group members would randomly be given a fictitious permit over their computers that allowed them to invest in the production account for the block of ten games. Those subjects that did receive a license would keep and retain that permit for the entire 10-game sequence. The licenses that the two group members would receive would also include an investment cap on the production account. License holding subjects were not capable of investing more than 7 tokens in the production account.[7] Those that would not be given a license were not capable of investing in the production account for the block of ten games. Non-permitted subjects would be aware of this fact, as the production account would entirely disappear from their screen during the ten game block. The only accounts available to them on their computer screen would then be the public and private accounts.

An outline of the session design can be found in Table 2. The session roadmap table illustrates each session type, number of games played, and the timing of treatment interven-

[7]Given the parameterization of the model in Table 1, capping investment at 7 tokens for only two subjects left to invest in the production account is equivalent to capping total group investment at the maximum sustainable yield.

tion.

It is not necessarily the interest of this experiment to address within-subjects how the implementation of this license policy would impact consumption and conservation. The reason *implementing* the policy is of little interest is because all 50 states already have license lottery systems in place for selected hunting and fishing permits. Though licensing policy may differ in several aspects across the U.S. the functions of the policies largely remain the same. Licenses are allocated via lottery, and licenses have quotas or specific caps on effort and investment in the resource extraction process.

The more interesting question generally considers what happens to consumption and conservation behavior within-subjects if the policies are later *revoked*. Because all 50 U.S. states already have similar hunting and fishing permit policies in some regard, the treatment order that is most meaningful to active environmental policy is therefore what happens when resource stakeholders already have this policy in effect and it is later rescinded.

Based on the theory constructed by the proposed model, and the experimental design outlined in this section, the following are the initial hypotheses to test experimentally:

- **H1: (Spillover Effect - PG)** The presence of resource spillovers will *ex ante* increase public good provision between blocks of games in which the combined CPR and PG game is played with and without resource account spillovers.

- **H2: (Spilllover Effect - CPR)** The presence of resource account spillovers will *ex ante* increase common pool investment between blocks of games with and without resource account spillovers.

- **H3: (Licensing)** The rescinding of a a licensing policy of capped investment for the common pool will *ex ante* increase common pool and public good investment.

- **H4: (Order Effects)** Individual level common pool investment will be increasing with respect to past group common pool investment, regardless of experimental treatment.

The first two hypotheses are derived from the symmetric Nash predictions for the combined game both with and without spillovers. The competitive equilibrium predicts no public good provision in the absence of resource account spillovers. In the presence of resource account spillovers there are two symmetric Nash Equilibria, the payoff dominant of which predicts equal investment in both the common pool and public good accounts. Because the payoff dominant equilibrium requires coordination of all group members to achieve, it is predicted that public good provision should be nonzero, or at the least higher than the baseline donations, if the decision-makers recognize that the PG spillover constitutes a threshold public good. The CPR hypothesis for the spillover effect predicts the same. The payoff dominant symmetric Nash Equilibrium with spillovers requires agents to invest one additional token towards the common pool. This means the range of optimal choices in CPR investment between treatments is only the difference of one token per agent, unlike the difference in public good provision where the range between optimal provision to the public good is between zero and five tokens per subject. Therefore it is anticipated for the CPR spillover effect to be a much weaker effect.

Hypotheses 3 is derived similarly to the new Nash predictions under the licensing policy treatment. With a capped licensing policy where only half of the group of resource stakeholders are allocated an allowance for CPR investment, we would indeed anticipate lower CPR investment. This effect comes from two sources, a decrease in group size investing in the common pool resource, and the licensing policy capping investment at the maximum sustainable yield. Because we predict a nonzero level of public good provision in the combined game with spillovers, we would anticipate public good provision to decrease with the licensing policy, as there is no longer the additional incentive for all stakeholders to benefit from the positive spillover that the public good has over the common pool resource.

Hypothesis 4 is a purely atheoretic and strictly experimental hypothesis for testing robustness of the information structure of the game. The goal is for the treatment effect for either resource account spillovers or licensing policy to be entirely uncorrelated to group decisions in previous games. Between all games, subjects see how many tokens their group invested in the common pool and public good. For this hypothesis to be true, we would expect that when the spillovers or license policy are enacted, their treatment effect is not influenced by the subjects seeing information from a the previous game played without the treatment in effect.

5 Results

Thus far, a total of 52 undergraduate subjects from FSU participated in the series of experiments examining the combined CPR and PG game with resource account spillovers as treatment, and 84 undergraduate subjects participated in the license policy treatment sessions. All 136 subjects were randomly placed into groups of four for the experiments, making for 13 total groups examined for the spillover treatment, and 21 total groups for the policy treatment. Four total sessions were conducted for the spillover treatment sequences, with 3 to 4 groups participating per-session. A total of 7 groups participated in the $A \rightarrow B \rightarrow A$ spillover treatment sequence, and 6 participated in the reverse treatment sequence. The policy treatment took place over a series of 6 laboratory sessions, with 3 to 4 groups participating per session. For both the spillover and policy treatment, sessions lasted 60 minutes and the average subject earned \$15.50, including a \$7.00 show-up fee.

Figures 5 and 6 illustrate the group level means of investment in both the CPR (production) and the linear public good (public) accounts for both described treatment sequences. For the NS/S/NS treatment sequence there is a high amount of public good provision early on however that quickly disappears midway through the block of games, prior to the spillover treatment being enacted in the sixth game. Once the spillover treatment is enacted for the ABA treatment sequence, there is a gradual increase in public good provision as the subjects learn that the positive PG spillover benefits CPR investment. This increase from the spillover treatment gradually disappears in a manner similar to "endgame trends" shown in the linear public goods experimental literature in the past. Following the tenth game, the spillover treatment disappears and we can see public good provisions return to a reduced level, however still positive.

For the reverse treatment sequence (S/NS/S) the opposite effect from the previous treatment sequence presents itself. Public good provision remains elevated for the first five games, and upon the resource account spillovers disappearing in the sixth game, public good provision dramatically decrease. This decreased level of public good provision remains prevalent until the resource account spillovers are reinstated following the tenth game of this treatment sequence. Following the reenactment of the resource account spillovers, from the eleventh game and onward there are, again, elevated levels of public good provision. The subjects get close to meeting the symmetric Nash Equilibrium hypothesis for the payoff dominant equilibrium, where common pool investment is equivalent to public good provision. At no point is this actually reached, however for four of the ten games played will account spillovers in this treatment sequence, it is observed that public good provision was actually in excess of common pool investment.

As expected, there is little change in common pool investment between games played with the spillover treatment, and baseline games without the account spillovers. In fact, the mean level of common pool investment was marginally higher in the baseline game versus the games played with account spillovers. Overall, the mean group investment in the common pool production account for baseline games was approximately 17.47 tokens for all sessions, while the mean group investment for the common pool was approximately 17.03 tokens games played with account spillovers, across all treatments. The difference between common pool investment with and without spillovers both evaluated within subjects and between subjects is not statistically significant at any conventional level, therefore hypothesis 2 is rejected, in regard to spillover effects on common pool investment.

Tables 3 and 4 illustrate the treatment effect of the resource account spillovers when evaluating within subjects and between subjects. Table 3 tests, for both session treatment sequences, the mean group public good provision within groups across games in which the resource account spillover treatment was changing. The top left quadrant of the table shows the treatment effect when the first five games played were the baseline, and the second block of five games (games 6-10) were with resource account spillovers turned on. This quadrant corresponds to comparing games 1-5 to games 6-10 of the NS/S/NS sessions. Given the results of the first five games in the NS/S/NS sequence, it is unsurprising that there is no significant difference between public good provision at any conventional level. Groups on average provided a high amount to the public good initially, before later reducing that provision. The bottom left quadrant compares games 6-10 to games 11-15 for the same NS/S/NS sessions. While this difference is still not significant at any conventional level, there is a much larger difference between public good investment with and without the spillovers. The upper and lower right quadrants of Table 3 show the corresponding results for the reverse spillover treatment sequence (S/NS/S). Within-subjects, removing the resource account spillovers significantly reduced public good provision in the middle block of five games, while reintroducing the spillovers later significantly increased provision again.

Overall, within-subjects analysis of this treatment effect partially supports Hypothesis 1 in all but the NS/S/NS treatment sequence. Because the reverse sequence order employed between sessions, I can also compare public good provision between subjects in the NS/S/NS and S/NS/S treatment sequences. The analysis for this between-subjects design is given in Table 4. Each row of Table 4 compares blocks of 5 games from each session sequence. The first row compares the first five games of the NS/S/NS session design to the first five games of the S/NS/S session design. This compares 5 periods of baseline games played to 5 periods of games with spillovers played, across sessions respectively. Between subjects, for the first five games played in either session, the resource account spillovers lead to a significantly higher level of public good provision. For the middle five games, where NS/S/NS sessions had the spillovers and S/NS/S sessions had no spillovers, there is not any significant difference. Recall there was an increase, within subjects, for the NS/S/NS sessions in this block of 5 games, however between subjects this difference disappears in comparison, as the NS/S/NS sessions level of "high provision" of the public good when facing spillovers was approximately the same as the baseline level of public good provision for groups in the reverse treatment order. Again, in the final five games played across sessions, the subjects in the S/NS/S sequence facing resource account spillovers provided significantly more towards the public good in comparison to the NS/S/NS subjects facing the game without spillovers in the final five games.

The resource account spillover treatment effects outlined in Tables 3 and 4 do provide evidence in support of Hypothesis 1, yet reject Hypothesis 2. Therefore the null hypothesis that the resource account spillovers have no effect on public good provision is rejected, but I fail to reject that there is no effect on common pool investment.

For robustness of the treatment effects against the information design, allowing subjects to see group level provision between games, I regressed past group decisions on current game level of individual investment, and included the spillover treatment effect. The results of the mentioned regressions are provided in Table 5. The outcome variables in both columns are the current game's level of individual CPR or public good investment. The lagged regressors are group level investments in the PG and CPR respectively, as well as however much of their 11 token endowment was saved, individually, in the private account. The lagged variables constitute information that each individual subject saw between games, regardless of session sequence. Each subject, between games played, would always see how many tokens their group totally invested in the CPR and how much their group totally invested in the PG account. The OLS estimates suggest that there is no correlation between the spillover treatment effect and any lagged variable. The only lagged variables that seem to have any real impact on the individual subjects' decisions were the groups total CPR investment from the previous period and the group's past public good provision. Therefore, there is no evidence to suggest that the spillover treatment effects are influenced by group decisions in previous periods.

Figures 7 and 8 map the group level mean investments for CPR and PG investment for the baseline game and game with spillovers, to put my results into the proper context of the prior CPR and PG literatures, as well as the context of the model constructed in this study. Figure 7 shows mean group investment in both accounts for the baseline combined game. Group investment in the common pool resource is quite close to the symmetric Nash prediction of 16 tokens total per-group. Like much of the experimental literature surrounding linear public goods, I do not observe either the Nash prediction of zero investment, nor the social optimum of investing all tokens not already invested in the common pool resource. Public good provision in baseline games consistently sits in an area between the Nash prediction and the social optimum. Figure 8 illustrates the same group means, however for games played with resource account spillovers in effect. As discussed previously, the mean level of CPR investment hardly changes when decision-makers face the spillover treatment. However, the mean public good provision does significantly increase, and approach the group level CPR investment. On the average, the difference between CPR investment and public good provision with spillovers is still positive. Meaning that the CPR still remains over-invested in, relative to the public good. In addition, this result also means that on average, groups were unable to trigger the positive spillover from sufficient public good investment. For every token invested in the CPR account beyond the threshold, another token would have to be provided to the public good to trigger the positive public good spillover. Although public good provision in the face of spillovers did exceed the spillover, because of the negative spillover from the CPR, groups were unable to trigger the positive spillovers from the public good.

For the license policy treatment sessions, Figure 9 shows mean group investments in the CPR and PG accounts over all 20 rounds that groups played. Similar to the spillover treatment sessions and inline with the experimental public goods literature, there is a significant nontrivial amount of investment in the PG account that is not suggestive of free riding. After the tenth round when the license policy is revoked, there was little to no change in the group level of PG investment, but a significant jump in CPR investment with all group members allowed to now invest.

Table 6 provides OLS estimates of the treatment effect of removing the licensing policy, controlling for several aspects of the laboratory environment. My controls include the maximum time it took the last subject in a group to submit their investment decisions per-round, the level of investment a group made in either resource account, and an indicator for a change in payment scaling[8]. Similar to the OLS estimates for the spillover treatment, I find that there is no correlation between the information structure of revealing group investments between rounds and subject response to the policy treatment. I find the removal of the licensing policy lead to an increase of 3.3 tokens invested per-subject in the CPR, while there is no discernible effect on the PG account. The effect of having a license for the first 10 rounds of the experiment is a relative increase of 5.3 tokens invested in the CPR and a reduction of 1 token invested in the PG account relative to those that did not hold a license for the first 10 rounds. The policy treatment for those with licenses for the first 10 rounds however is not 3.3 tokens, as described earlier. Those that had a license consistently invested approximately 1 token less in the final 10 rounds than they did in the first 10.

Estimates of the treatment effect of removing this policy can be found in Tables 7 and 8, illustrating the policy effect on the CPR and PG respectively. Paired t-tests of group investment in either account supports a significant increase in CPR investment following the removal of the policy, but not noticeable change in PG investment. The lower two panels of the tables test the difference in levels of investment in either account between those that held a license for the first 10 rounds of the experiment and those that did not. After the licensing policy is removed, there is no discernible difference in the investment decisions

[8]The first two sessions of this laboratory experiment were conducted with the same exchange rate of $100ECU = \$1.00$, however this led to extremely high payments for subjects (\$20 to \$30) for a 60 minute experiment. The exchange rate was increased to $180ECU = \$1.00$, to bring the average pay closer towards the spillover treatment sessions

between those that had a license and those that did not, in either resource account. What is most fascinating is a reversal of PG investment between those that did and did not hold licenses. In the first 10 rounds of the experiment, those that did not hold a license consistently invested 1 more token towards the public good than those that held a license. Following the removal of the license policy that precluded some subjects from investing in the CPR, those that originally held a license increased their level of PG investment while those that originally had no license invested less in the PG for the final 10 rounds. This results in a switch in PG provision, with those originally holding a license now providing the majority share of the PG investment following the removal of the policy.

One reason a budget of 11 tokens was implemented was so that the budget could not be evenly split between all three accounts. This creates a cutoff threshold, *ex ante*, to classify subject investments on the domination and mutualism scales, using CPR investment and PG investment as proxies for each respectively. The average individual CPR and PG investments are taken from rounds subjects played with the resource account spillovers in effect and no other treatment in effect. I choose the spillover rounds to calculate the average as that creates a uniform method classifying subjects across the spillover and policy treatment sessions, while also not biasing the averages towards 0 by potentially including observations from the policy treatment sessions where a subject without a CPR license could not feasibly invest in the CPR.

I classify subjects as high-domination oriented if they invested an average of 4 or more tokens in the CPR account, while investing less than 4 tokens on average in the PG account. High-mutualism are classified as the opposite; investing on average less than 4 tokens in the CPR while investing 4 or more tokens on average towards the PG account. Subjects are classified as pluralists if they invested an average of 4 or more tokens in both the CPR and PG account, while subjects are classified as distanced oriented if they invested an average of less than 4 tokens in both resource accounts. The distributions of subject classifications for the spillover treatment and license policy treatment sessions are provided in Figures 10 and 11.

One motivation for such classifications is to observe how the treatments impact the level of investment within the preference orientation of each type of subject. Figure 12 illustrates the mean individual investment between all 4 classifications for the spillover treatment sessions. Overall, there is little change in investment between either resource account due to the presence of resource spillovers. Those that have a proclivity to spend some amount on any single resource account are not shaken from that balance of payments by the presence of resource externalities. The same cannot be said, however, for the license policy treatments, which can be found in Figure 13. While there is little impact to the domination oriented and pluralist subjects, those with a mutualist orientation and those distanced significantly increase their level of investment in the CPR following the removal of the policy. Even those with little proclivity to invest in the CPR begin to invest when the license policy is revoked, even if they were capable of investing in the CPR with the license policy in effect.

Across all policy treatment sessions, there is little to no change in earnings amongst the observed groups following the removal of the licensing policy. Tables 9 and 10 provide tests of the licensing policy treatment effect across groups and between those that held and did not hold a license when the policy was in effect. Subjects that held a license for CPR investment in the first half of the experiment initially earned \$0.33 more per-game than those without a license. Once the policy was removed, the reduction in earnings for those that once held a license was approximately equal to the gain in earnings for the subjects without a license. The corresponding reduction in earnings for the former group and increase in earnings for the latter balance out to the point where there is no difference in earnings between subjects that once did or did not hold a CPR License.

The results of Tables 9 and 10 are based on average group and individual-level outcomes. While there is no statistical change in group welfare, without the licensing policy preventing the negative CPR spillover on the public good, groups began to face instances of the negative spillover with the increase in CPR investment. When the license policy was removed subjects exceeded the CPR threshold and did not meet the PG threshold in three out of the 10 games played on average. For comparison, with the license policy in effect there was no possibility of the CPR threshold being crossed and groups only failed to meet the PG threshold in approximately 1 out of the 10 games played. Despite no change in group earnings following the policy removal, there is a corresponding increase in likelihood that groups inefficiently cross the CPR threshold and reduce the public good's value.

6 Conclusion and Extensions

Despite the many scenarios in the natural resource field for which we can model resource use as a multidimensional problem of domination (consumption) and mutualism (consumption) there has been little exploration of this topic. This paper contributes to the natural resource and experimental literature by allowing a resource pool to have both value in depletion and conservation. Moreover, the model and experiment allow for policy and externalities based on nature to be explored in this economic setting.

My model introduces a combined resource pool game in which there is a common pool investment (consumption) aspect and a public good donation (conservation) aspect, that extends problems of resource management across two separate, but connected dimensions.

I employ externalities modeled off of resource decay and positive trophic spillovers to understand how negative and positive shocks to a multidimensional resource pool impacts preferences towards resource consumption and conservation. To test the hypotheses generated by this combined model and the resource spillovers, I parameterize the game and spillover treatments for a laboratory setting, varying the spillover treatment across intervals of games played in groups.

I find that across all groups, the presence of resource account spillovers significantly improve the provision of a public good that is meant to represent conservation effort for the resource pool. The spillovers likewise have little to no actual impact on investment effort on the common pool aspect of the resource pool. This presence of this treatment effect helps illustrate how the benefits of conservation are most often realized by the appropriators of a resource. Moreover, the positive result observed for public good provision illustrates how those providing towards conservation effort are often the resource appropriators themselves.

Evaluating an investment capped license lottery policy motivated by active US hunting and fishing policy I find that upon removing such a policy from this multidimensional resource pool environment there is a significant increase in common pool investment. Those who were once precluded from investing in the CPR are the major contributors to this effect, as those that had previously been allocated licenses marginally decreased their investment when their full group was able to utilize the CPR account. While there were periodic instances of the resource pool collapsing from this heightened investment, there is no evidence to suggest there is a decrease in the average group's welfare.

To reiterate a point made previously in Section 3, the theorized license policy I evaluate in this laboratory environment is a "perfect" policy. In the laboratory experiment, there is no possibility of subjects cheating and consuming from the common pool without a license. Moreover, the investment cap placed on the licenses is perfectly set at the maximum sustainable yield, therefore there is no environmental uncertainty nor possibility subjects to exceed the CPR spillover threshold with the policy in effect. Evaluating the licensing policy under this perfect scenario, I find that subjects are on average no better or worse off with or without the policy in effect. Active statewide hunting and fishing policy can never be as perfect as is modeled in this experiment due to environmental uncertainty surrounding maximum sustainable yields, and the nontrivial possibility of poaching. Therefore, it is entirely possible that the removal of a common pool licensing policy with environmental or institutional uncertainty could exacerbate resource collapse.

Extensions to future work will account for the ability for subjects to cheat on licenses, or quite literally "poach" from the common pool. Additionally, incorporating environmental uncertainty on the externality threshold between resource accounts presents itself as a future extension. Common pool threshold uncertainty and ambiguity through laboratory experiment is a growing and valuable literature given the problems presented by climate change for resource managers. Incorporating threshold ambiguity, such as those modeled in Aflaki (2013) and Ahsanuzzaman, Palm-Forster, and Suter (2022). Further extensions may include group entry uncertainty, adding the possibility of stakeholder group size to increase in the absence of a licensing policy.

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A Tables

Table 1: Experiment Parameterization

Experiment Characteristics	No Spillovers (Baseline)	Account Spillovers (Externality Treatment)
Group Size	4	4
CPR and PG Token Threshold	-	14
Individual Token Endowment	11	11
CPR Production	$F(\sum x) = 14\sum x - 0.5(\sum x)^2$	$F(\sum x) = 14\sum x - 0.5(\sum x)^2$
CPR Production (PG threshold met)	-	$F_H(\sum x) = 24\sum x - 0.8(\sum x)^2$
PG Production	$G(\sum d) = 2\sum d$	$G(\sum d) = 2\sum d$
PG Production (CPR Threshold Exceeded)	-	$G(\sum d) = 2(\sum d - \sum x + 14)$
Private Account Marginal Return	4	4
Dominant Nash EQ CPR Investment	16	20
Dominant Nash EQ PG Investment	0	20
Social Optimum CPR Investment	10	12.5
Social Optimum PG Investment	34	31.5

Table 2: Experimental Session Roadmap

Session Design	Number of Games	Games 1-5	Games 6-10	Games 11-15	Games 16-20
NS/S/NS	15	No Spillovers	Spillovers	No Spillovers	-
S/NS/S	15	Spillovers	No Spillovers	Spillovers	-
CPR License Policy	20	License Policy	License Policy	No License Policy	No License Policy

Table 3: Tests for Spillover Treatment Effect on Public Good Investment (Within Subjects)

NS/S/NS Sessions	Obs	Mean	Std. Dev.	S/NS/S Sessions	Obs	Mean	St. Dev.
No Spillover Games (Games 1-5)	7	12.171	4.091	Spillover Games (Games 1-5)	6	17.467	4.158
Spillover Games (Games 6-10)	7	13.486	1.408	No Spillover Games (Games 6-10)	6	12.233	2.693
T-Score		-0.628		T-Score		2.587***	
Spillover Games (Games 6-10)	7	13.486	3.725	No Spillover Games (Games 6-10)	6	12.233	2.693
No Spillover Games (Games 11-15)	7	10.686	4.113	Spillover Games (Games 11-15)	6	14.833	3.148
T-Score		1.335		T-Score		-1.537*	

Table 4: Tests for Spillover Treatment Effect on Public Good Investment (Between Subjects)

	NS/S/NS		S/NS/S		
Games	Mean	Std. Dev.	Mean	Std. Dev.	T-Score
1-5	12.171	4.091	17.467	4.158	-2.309**
6-10	13.486	3.725	12.233	2.693	0.683
11-15	10.686	4.113	14.833	3.148	-2.012**

Table 5: Treatment Effect on Account Spending (OLS)

Independent Variables	CPR Spending	PG Spending
Spillover Indicator	1.055	1.624
	(1.075)	(1.085)
CPR Lag	0.007	0.099***
	(0.035)	(0.022)
PG Lag	0.011	0.059***
	(0.013)	(0.019)
CPR Lag x Spillover	-0.049	-0.038
	(0.047)	(0.034)
PG Lag x Spillover	-0.020	-0.004
	(0.016)	(0.020)
Constant	3.937***	-0.128
	(0.695)	(0.843)
Obs	560	
R^2	0.0052	0.0907

Reported standard errors are clustered at the group level.

Table 6: License Policy Treatment Effect on Account Spending (OLS)

Independent Variables	CPR Spending	PG Spending
License Treatment Effect	3.288***	-0.769
	(0.554)	(0.706)
License Holder Indicator	5.339***	-1.103**
	(0.190)	(0.447)
License Holder x Treatment	-4.956***	1.596***
	(0.556)	(0.506)
Time Lag	-0.004***	-0.001
	(0.001)	(0.001)
Time Lag x Treatment	0.002	0.005*
	(0.003)	(0.003)
CPR Lag	0.058***	0.030
	(0.018)	(0.019)
PG Lag	0.020*	0.141***
	(0.011)	(0.022)
CPR Lag x Treatment	-0.021	0.007
	(0.035)	(0.029)
PG Lag x Treatment	0.010	-0.014
	(0.014)	(0.019)
Pay Scale Change	0.299	-0.116
	(0.201)	(0.235)
Pay Scale x Treatment	0.505*	-0.497
	(0.275)	(0.318)
Constant	-0.858***	2.037***
	(0.323)	(0.568)
Obs.	1680	
R^2	0.5071	0.1061

Reported standard errors are clustered at the group level.

Table 7: License Policy and License Holding Effects on CPR Investment

Policy Effect	Obs	Mean Group Investment	Std. Dev.	T-Score
Licensing Policy (Games 1-10)	21	10.738	1.899	-7.206***
No Licensing Policy (Games 11-20)	21	16.738	3.310	
Licensure Effect (Games 1-10)	**Obs**	**Mean Individual Investment**	**Std. Dev**	**T-Score**
Licensed	42	5.340	1.380	-25.077***
Not Licensed	42	0	0	
Licensure Effect (Games 11-20)	**Obs**	**Mean Individual Investment**	**Std. Dev.**	**T-Score**
Licensed	42	4.321	1.957	-0.890
Not Licensed	42	3.938	1.992	

Table 8: License Policy and License Holding Effects on PG Investment

Policy Effect	Obs	Mean Group Investment	Std. Dev.	T-Score
Licensing Policy (Games 1-10)	21	15.619	4.964	0.395
No Licensing Policy (Games 11-20)	21	15.052	4.336	
Licensure Effect (Games 1-10)	**Obs**	**Mean Individual Investment**	**Std. Dev**	**T-Score**
Licensed	42	3.264	1.490	2.461***
Not Licensed	42	4.350	2.441	
Licensure Effect (Games 11-20)	**Obs**	**Mean Individual Investment**	**Std. Dev.**	**T-Score**
Licensed	42	4.086	1.855	-1.150
Not Licensed	42	3.595	2.050	

Table 9: License Policy and License Holding Effects on Profit (USD)

Policy Effect	Obs	Mean Group Profit	Std. Dev.	T-Score
Licensing Policy (Games 1-10)	21	2.239	0.743	0.977
No Licensing Policy (Games 11-20)	21	1.991	0.898	
Licensure Effect (Games 1-10)	**Obs**	**Mean Individual Profit**	**Std. Dev.**	**T-Score**
Licensed	42	0.723	0.271	-7.043***
Not Licensed	42	0.393	0.145	
Licensure Effect (Games 11-20)	**Obs**	**Mean Individual Profit**	**Std. Dev.**	**T-Score**
Licensed	42	0.503	0.256	-0.195
Not Licensed	42	0.493	0.234	

Table 10: License Policy Effect on Profit by Licensed Status (USD)

Policy Effect	Obs	Mean Profit For Licensed Subjects	Std. Dev.	T-Score
Licensing Policy (Games 1-10)	42	0.723	0.271	3.891***
No Licensing Policy (Games 11-20)	42	0.503	0.256	
Policy Effect	**Obs**	**Mean Profit For Subjects Not Licensed**	**Std. Dev**	**T-Score**
Licensing Policy (Games 1-10)	42	0.393	0.145	-2.346**
No Licensing Policy	42	0.493	0.234	

B Figures

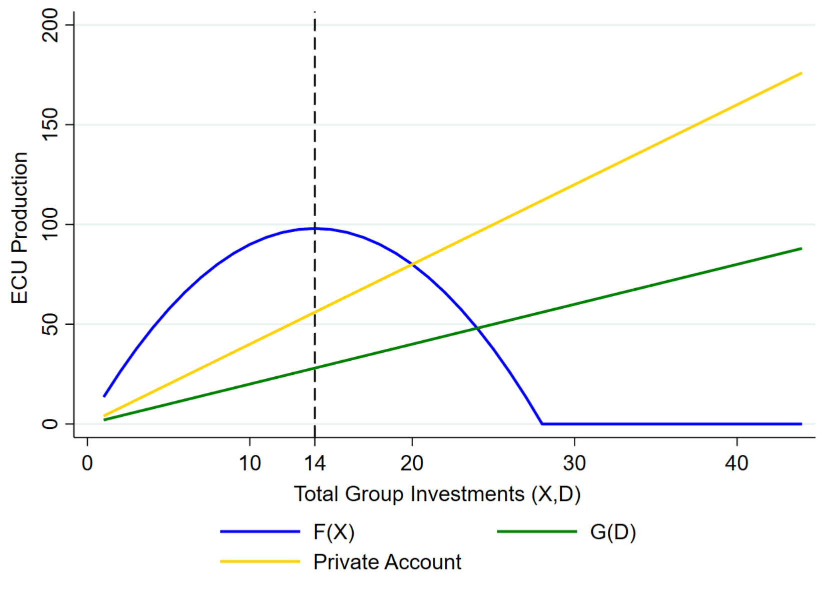


Figure 1: Baseline Game Group Production Functions

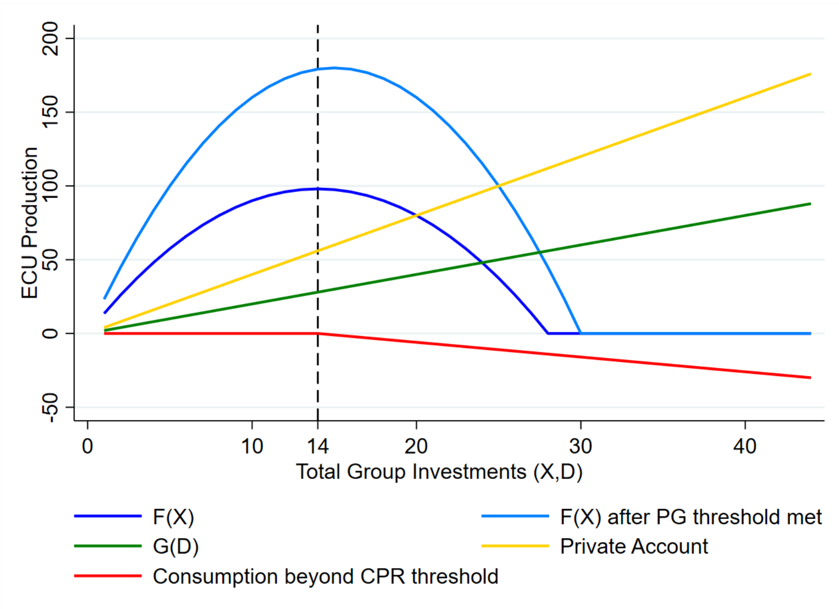


Figure 2: Group Production Functions with Spillovers

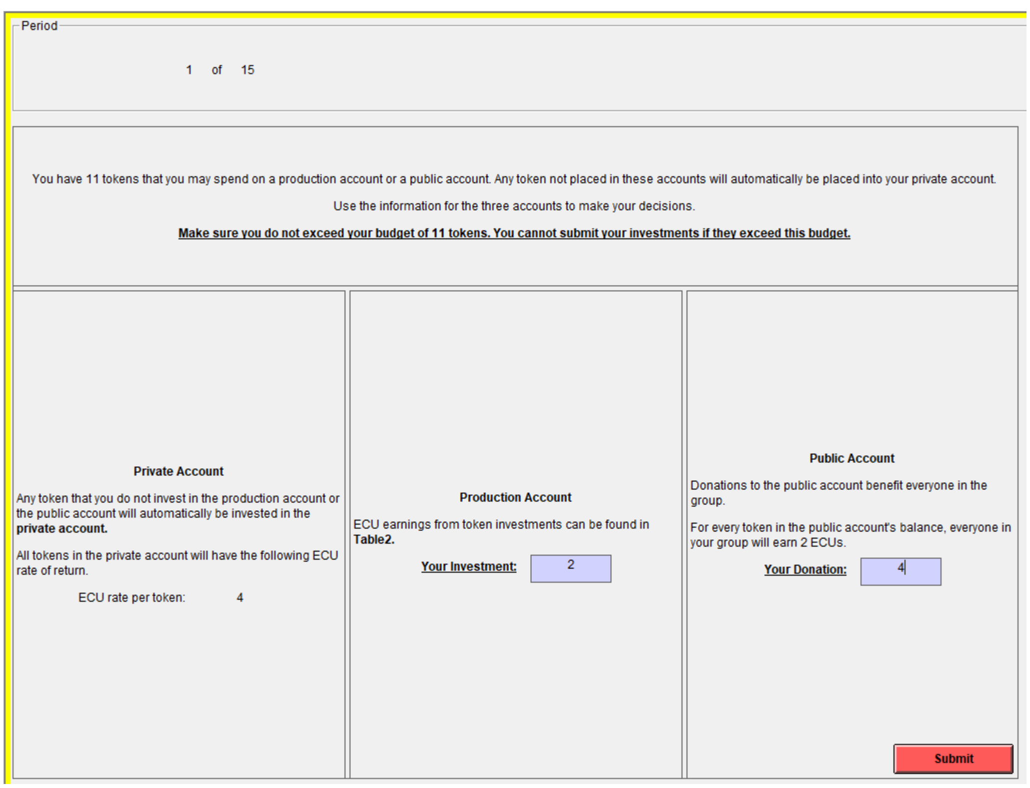


Figure 3: zTree Interface

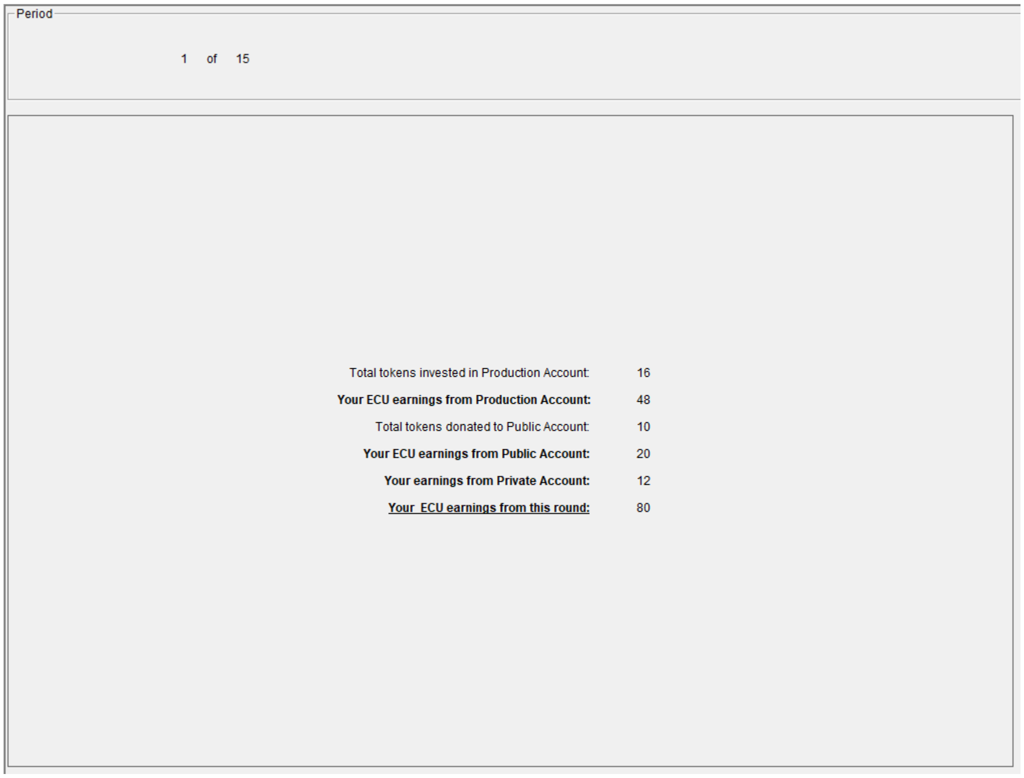


Figure 4: End of Game Information Screen

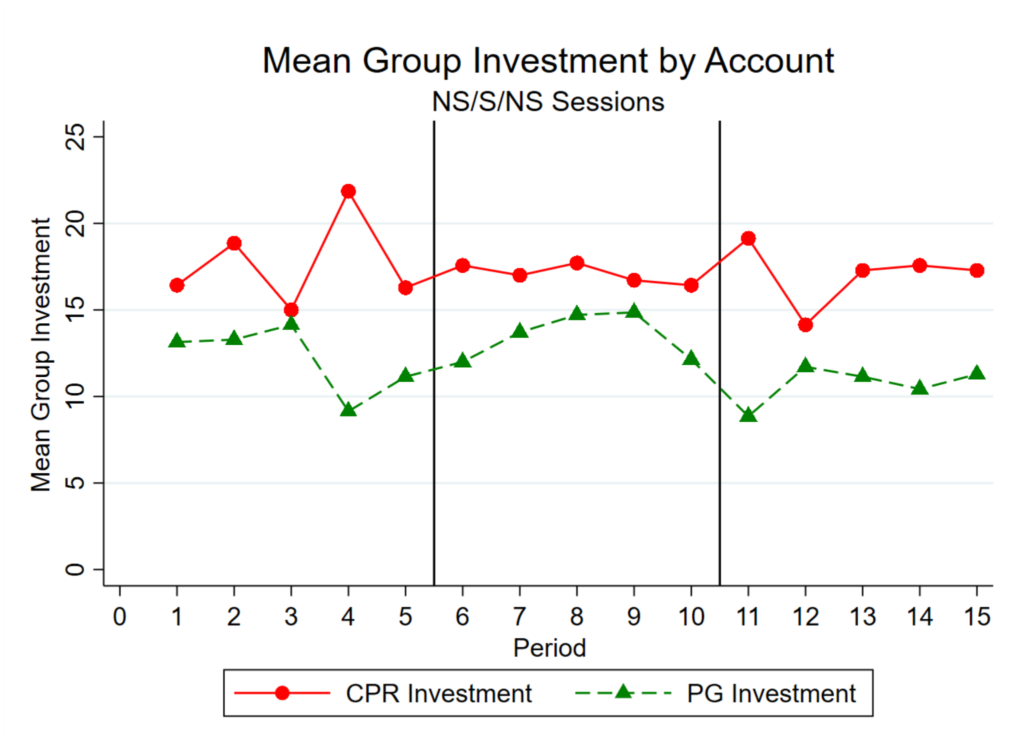


Figure 5

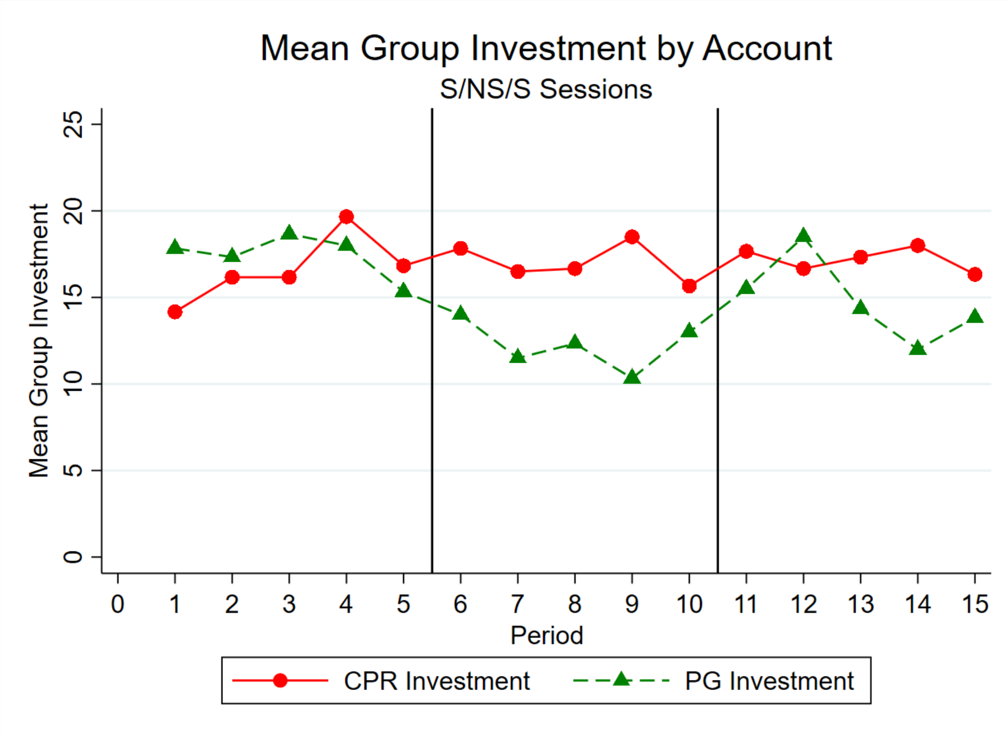


Figure 6

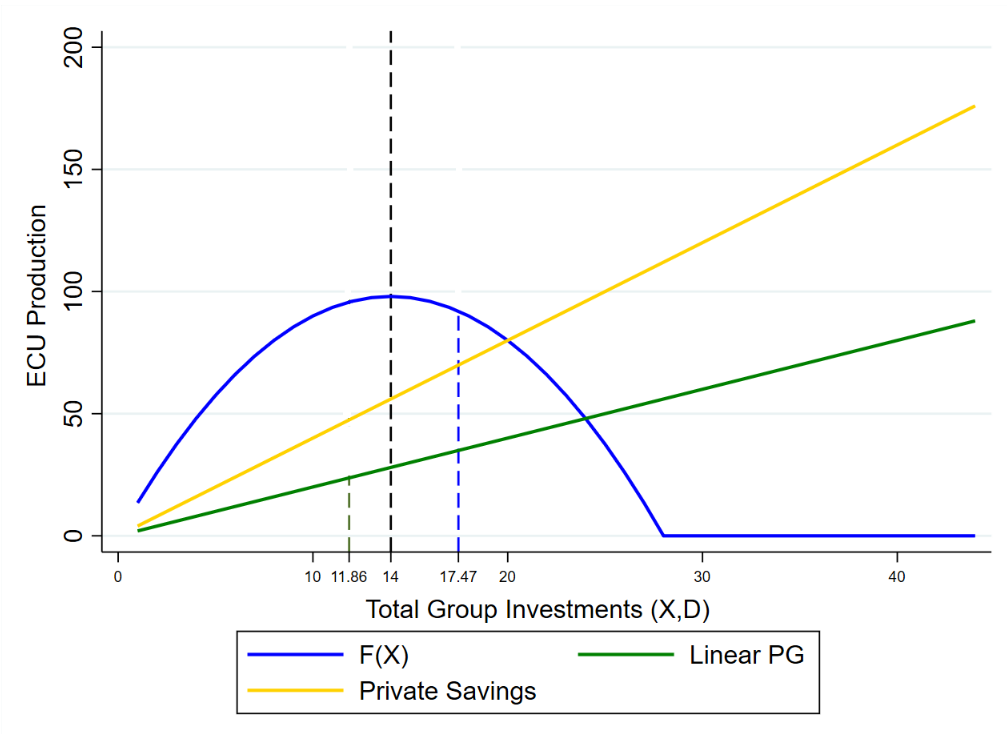


Figure 7: Baseline Group Production Functions with Group Mean Investments

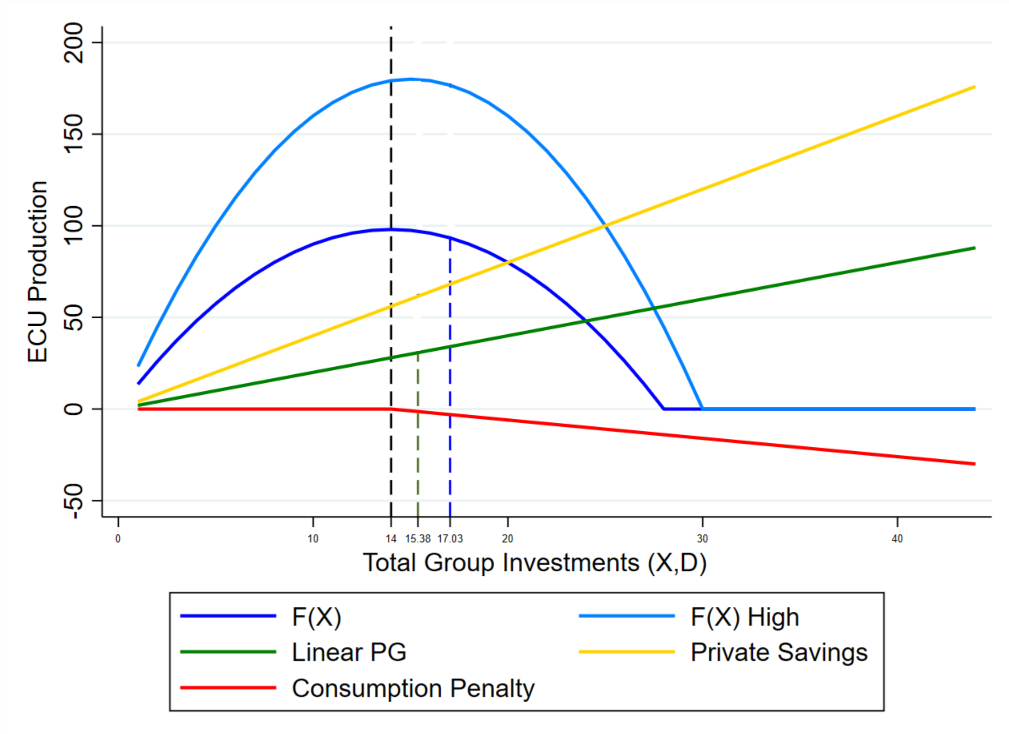


Figure 8: Group Production Functions with Spillovers, and Group Mean Investments

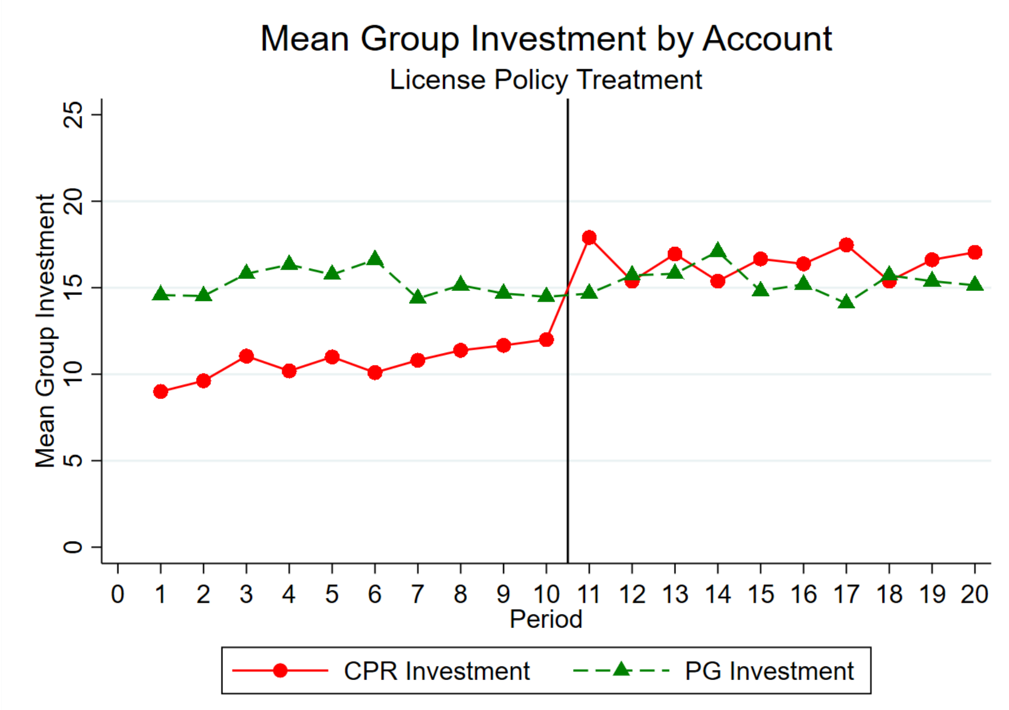


Figure 9

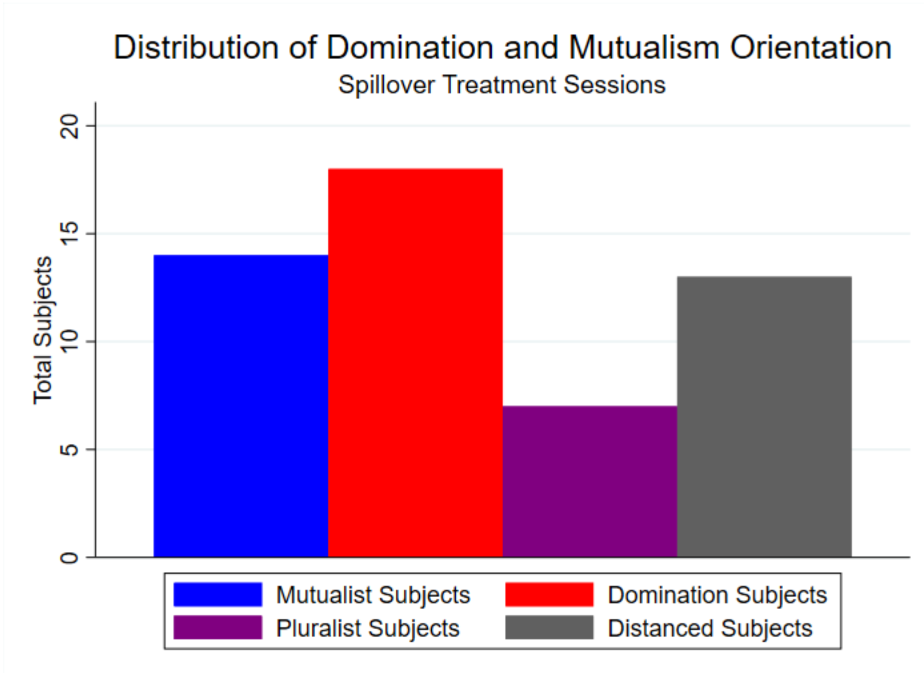


Figure 10

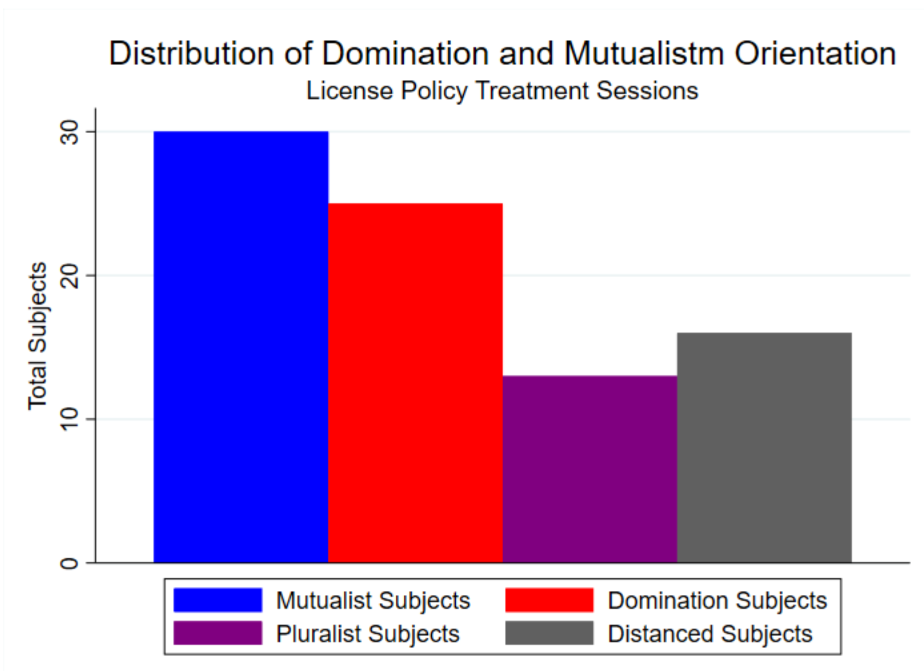


Figure 11

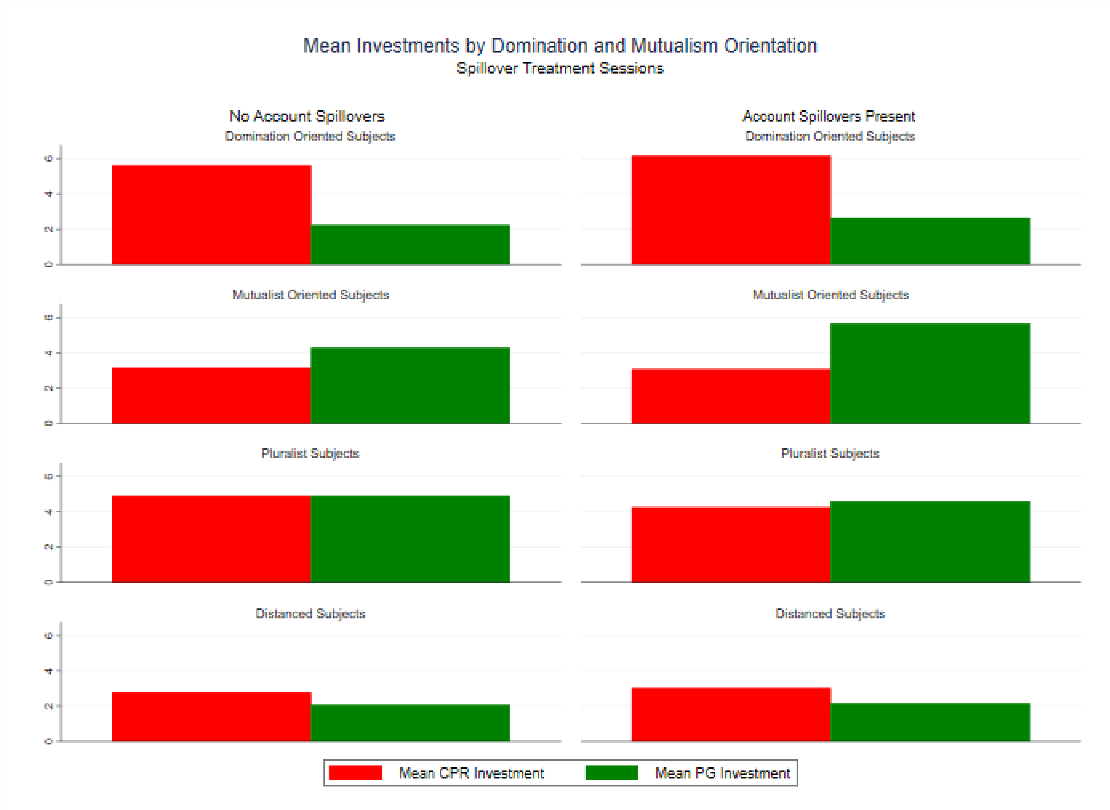
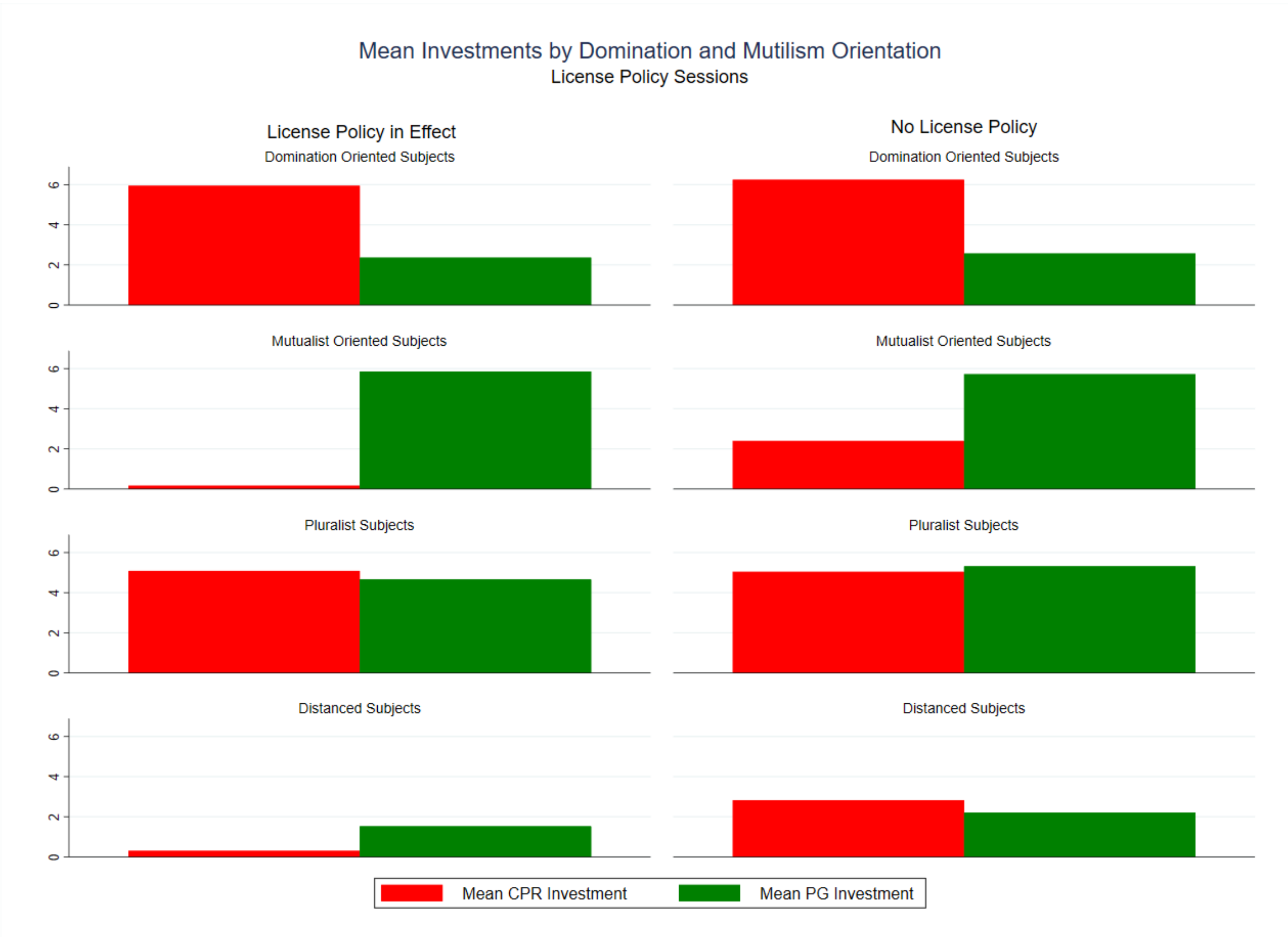

Mean Investments by Domination and Mutualism Orientation
Spillover Treatment Sessions
No Account Spillovers
Domination Oriented Subjects
Account Spillovers Present
Domination Oriented Subjects
Mutualist Oriented Subjects
Mutualist Oriented Subjects
Pluralist Subjects
Pluralist Subjects
Distanced Subjects
Distanced Subjects
Mean CPR Investment
Mean PG Investment

Figure 12



Mean Investments by Domination and Mutilism Orientation
License Policy Sessions
License Policy in Effect
No License Policy
Domination Oriented Subjects
Mutualist Oriented Subjects
Pluralist Subjects
Distanced Subjects
0
2
4
6
Mean CPR Investment
Mean PG Investment

Figure 13

C Proofs and Comparative Statics of the Model

Functional Forms:

Let $F(\sum x_j)$ be of the form

$$F(\sum x_j) = a\sum x_j - b(\sum x_j)^2$$

where $a > 0$ and $b > 0$.Moreover, let $F(\sum x_j)$ be s.t. $F'(0) > w$, $F'(ne) \leq 0$, and $F'(nw) = a - 2bnw < 0$. Lastly, suppose the MPCR of the linear PG is s.t. $0 < \alpha \leq w$. The individual profit function for the combined resource pool game is then:

$$\pi_i(x_i, d_i) = w(e - x_i - d_i) + \frac{x_i}{\sum x_j} F(\sum x_j) + \alpha \sum d_j$$

For resource account spillovers, let τ_c,$\tau_p \in R^+$ be externality thresholds, and not necessarily equal. Using externalities defined in Secion 2,

Comparative Statics of τ_p and τ_c:

Suppose τ_p is large enough s.t. $\sum x_j < \tau_p$ is true when $\sum d_j \geq \tau_p$ and $\exists Y \leq \sum d_j$ s.t. $F_s(\sum x_j) < F(Y)$, $\forall \sum x_j \leq ne - \tau_p$, then $\sum x_j = \frac{n}{n+1}\frac{a-w}{b}$ and $\sum d_j = 0$ constitutes a unique symmetric Nash Equilibrium of the combined resource game with externalities. At this local maximum, any additional token invested in the CPR has a negative marginal return given $F(\cdot)$. Moreover, any additional token donated to the PG has a marginal return of α, and $0 < \alpha \leq w$. Meaning that token is better off spent on the private account. Even if $\sum x^* > \tau_c$ (meaning PG provision decreases by $\sum x^* - \tau_c$ tokens), because $w \geq \alpha$, the gains from saving that token in the private account exceed the losses on the public good. However if the converse is true, then the symmetric Nash Equilibrium described by equations (10) and (11) of Section 2 is also a symmetric Nash Equilibrium, and constitutes a payoff dominant equilibrium. Therefore, $\sum x^*$ is non-increasing and $\sum d^*$ is non-decreasing w.r.t τ_p.

In the presence of the defined resource externalities, $\sum x^*$ and $\sum d^*$ are both non-decreasing w.r.t τ_c. This result follows from the definition of the CPR negative spillover. The PG balance decreases one to one by the quantity $\sum x_j - \tau_c$. Changes to τ_c alter the boundary condition that makes the Nash Equilibrium defined by equations (10) and (11) feasible.

Social Dilemmas with Capped CPR Licenses

As is the case in the laboratory experiment, let $\tau_p = \tau_c = \tau$ be a single uniform threshold for both resource accounts. Under the policy of CPR licensing defined in Section 3, suppose the social dilemmas in the CPR and PG accounts are strictly less than those present without the licensing policy. This means we have that

$$(\sum x^{SO} - \sum x^*) + (\sum d^{SO} - \sum d^*) > (\sum x_L^{SO} - \sum x_L^*) + (\sum d_L^{SO} - \sum d_L^*)$$

Because $\sum x^{SO} = \sum x_L^{SO}$, $\sum d^{SO} = \sum d_L^{SO}$, and the payoff dominant symmetric Nash Equilibrium for the game with externalities has $\sum x^* = \sum d^*$ this inequality reduces to

$$\sum x_L^* - 2\sum x^* > 0$$

or

$$\sum x_L^* > 2\sum x^*$$

This is a contradiction as $\sum x_L^* < \sum x^*$. Therefore, under the licensing policy, the CPR and PG social dilemmas present with the modeled licensing policy are greater than or equal to those without the policy.

D Instructions

General Instructions (Spillover Treatment Sessions)

General Information: The purpose of this experiment is to study how people make decisions in an environment in which there is a shared resource that may be competitively produced while also be produced in a way that benefits all. From now and until the end of the experiment any verbal or written communications with other participants is not permitted. If you have a question, please wait until all instructions have been read. If you have a question after the instructions have been read, please raise your hand and the experimenter will be with you as soon as available.

You will receive $7.00 for showing up on time for the experiment. In addition, you will have an opportunity to earn more money during the experiment. All currency in this experiment will be denominated in Experimental Currency Units (ECU's). At the end of the experiment, those ECU's will be translated into U.S. currency at the rate of 100 (ECUs)= $1.00. At the end of the experiment you will be paid, in cash, the sum of your show-up fee and earnings from the experiment. You will be paid privately and we will not disclose any identifiable information about your decisions or payment to other participants in the experiment. For ease of payment, all earnings will be rounded up to the nearest quarter to keep loose change to a minimum.

Groups and Rounds:

Today, you will be placed into groups with 3 other participants. The decisions of the groups are completely independent in each round. That is to say, nothing Group 1 does will affect the other groups at any point of the experiment, and vice versa.

Today's experiment will consist of 15 independent "rounds", each lasting no longer than 3 minutes. Each round you will be placed into a random group with 3 other participants. These rounds are the screens where you will be making decisions that will be described in the next section. Once again, independent here means that any decision made in one round will not affect what happens in any other round. You will not be able to see the individual decisions of your fellow group members, however at the end of each round you will see the overall outcome for your group, as well as your earnings from that specific round.

At the end of the experiment, after the 15th round you will see a payoff screen that tells you how many ECU's you have earned from each round, and what your final total payoff is in U.S. currency.

Description of Decisions, Accounts, and Payoffs:

Decisions:

In each round, you and your group will be tasked with making investment decisions in three different accounts: a production account, a public account, and a private account.

Each of you will be given an endowment of 11 tokens for each round to use as a budget. These tokens are what you will use to invest in each of the three accounts. When you invest your tokens, the computer will tally up your and your group members' investments and convert your tokens into an ECU payment. You cannot exceed this budget. If you attempt to invest more than 11 tokens, the computer will give you a message box reminding you of this constraint.

Production Account:

The production account is an account where you and your group may invest your tokens to produce a pile of ECUs, that will be split amongst you and your group according to how much you invested relative to the rest of your group. Mathematically, the return on this account is equal to:

$$ECUs = \frac{(Your\,investment)}{(Group\,investment)}[14 * (Group\,investment) - 0.5 * (Group\,investment)^2]$$

The return on investment from the production account is also described in Table 2. The columns of table 2 show your return for the production account based on how many tokens you invest, while the rows show your return based on how many tokens the rest of your group invests. For example, column 3 row 9 shows you how much you would earn from this account if you invest 3 tokens and the other 3 members of your group invest a total of 9 tokens to the production account.

Public Account: The public account is an account where you and your group may invest your tokens to produce ECUs for the entire group. Each token invested in the public account increase everyone's earnings by 2 ECUs. Mathematically this is equivalent to:

$$ECUs = 2 * Total\, token\, balance$$

Private Account:

The private account is an account where you can save any tokens you would not like to invest in either the production account or public account. As the name suggests, the private account is entirely private, therefore any token you save will go towards your earnings alone. Each token that is saved in the private account will be converted into 4 ECUs at the end of the round. So, if I were to save 5 of my 11 tokens, then I would earn 20 ECUs from the private account at the end of the round. You do not actively place tokens in the private account. From your budget of 11 tokens, your private account savings are simply determined to be however many of the 11 tokens you have not placed in either the production or public accounts. As an example, suppose I invest 4 tokens in the production account, and invest 2 tokens towards the public account. My private account savings would then be calculated based on my leftover tokens, i.e. the 4 tokens I have not invested. Because any token invested into the production or public accounts is automatically placed in the private account, if you choose to not invest any tokens, your entire endowment will automatically be saved in the private account. Similarly, if you do not submit your investment decisions within the 3-minute time period, your entire endowment will be placed in the private account as well. Even if you have typed some investment decisions into the account boxes, if you do not hit the submit button in the lower right corner of the screen, your entire endowment will go to the private account.

Account Spillovers:

For rounds 1-5 and 11-15, your group will play the game as described up to this point. However, for rounds 6-10, there will be spillovers between the production and public accounts based on your investment decisions. These spillovers are triggered if and only if your group's investment decisions in either account exceed a certain threshold. These spillovers are effects from one account that affects another, i.e., production account influencing the public account and vice versa.

Production spillovers:

If your group's token investment in the production account exceeds a total of 14 tokens, then any additional token invested in the production account will reduce the public account balance by 1 token. For example, suppose my group's investment in the production account is 15 tokens in a round when the production spillover is in effect. With the threshold of 14 tokens, that means the 15th token that is spent, reduces the balance of tokens we've invested to the public account by 1. Keep in mind, this also means that the public account can turn negative depending on how much you invest in the production and public accounts.

Public spillovers:

If your group's public account balance is at least 14 tokens, then the production account will become more productive.

The new production function that is applied when this spillover is triggered is:

$$ECUs = \frac{(Your\, investment)}{(Group\, investment)} * [24 * (Group\, investment) - 0.8 * (Group\, investment)^2]$$

The return on your investment on this more productive account can be found in Table 3. This table can be read in the same way as table 2. As you can see in table 3, each cell has a higher payoff than the corresponding cell from table 2.

Keep in mind how these spillovers are defined. While the public account spillover makes the production account more productive, the production account spillover reduces how many tokens are in the public account. This means that for every token invested in the production account beyond the threshold of 14, you will need an additional token invested in the public account to trigger the public account spillover. An example of this, suppose my group has chosen to invest exactly 14 tokens in the public account and 15 tokens in the production account. Because we exceeded the production account threshold by 1 token, this means the tokens in the public account decrease by 1, due to the spillover from the production account. This means we will need yet another additional token invested to the public account in order to trigger the public account's spillover.[9]

[9] Instructions for the BAB sequence sessions were identical. The only difference was in the *Account Spillovers* section. The rounds in which the treatment took effect were reversed.

Table 2: Baseline ECU Earnings From Production Account Based on Tokens Invested.

Tokens invested by group members in production account	Your tokens invested in production account: 0	1	2	3	4	5	6	7	8	9	10	11
0	0	13.5	26	37.5	48	57.5	66	73.5	80	85.5	90	93.5
1	0	13	25	36	46	55	63	70	76	81	85	88
2	0	12.5	24	34.5	44	52.5	60	66.5	72	76.5	80	82.5
3	0	12	23	33	42	50	57	63	68	72	75	77
4	0	11.5	22	31.5	40	47.5	54	59.5	64	67.5	70	71.5
5	0	11	21	30	38	45	51	56	60	63	65	66
6	0	10.5	20	28.5	36	42.5	48	52.5	56	58.5	60	60.5
7	0	10	19	27	34	40	45	49	52	54	55	55
8	0	9.5	18	25.5	32	37.5	42	45.5	48	49.5	50	49.5
9	0	9	17	24	30	35	39	42	44	45	45	44
10	0	8.5	16	22.5	28	32.5	36	38.5	40	40.5	40	38.5
11	0	8	15	21	26	30	33	35	36	36	35	33
12	0	7.5	14	19.5	24	27.5	30	31.5	32	31.5	30	27.5
13	0	7	13	18	22	25	27	28	28	27	25	22
14	0	6.5	12	16.5	20	22.5	24	24.5	24	22.5	20	16.5
15	0	6	11	15	18	20	21	21	20	18	15	11
16	0	5.5	10	13.5	16	17.5	18	17.5	16	13.5	10	5.5
17	0	5	9	12	14	15	15	14	12	9	5	0
18	0	4.5	8	10.5	12	12.5	12	10.5	8	4.5	0	0
19	0	4	7	9	10	10	9	7	4	0	0	0
20	0	3.5	6	7.5	8	7.5	6	3.5	0	0	0	0
21	0	3	5	6	6	5	3	0	0	0	0	0
22	0	2.5	4	4.5	4	2.5	0	0	0	0	0	0
23	0	2	3	3	2	0	0	0	0	0	0	0
24	0	1.5	2	1.5	0	0	0	0	0	0	0	0
25	0	1	1	0	0	0	0	0	0	0	0	0
26	0	0.5	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0

Table 3: ECU Earnings From Production Account Based on Tokens Invested with Spillover.

Tokens invested by group members in production account	Your tokens invested in production account											
	0	1	2	3	4	5	6	7	8	9	10	11
0	0	23.2	44.8	64.8	83.2	100	115.2	128.8	140.8	151.2	160	167.2
1	0	22.4	43.2	62.4	80	96	110.4	123.2	134.4	144	152	158.4
2	0	21.6	41.6	60	76.8	92	105.6	117.6	128	136.8	144	149.6
3	0	20.8	40	57.6	73.6	88	100.8	112	121.6	129.6	136	140.8
4	0	20	38.4	55.2	70.4	84	96	106.4	115.2	122.4	128	132
5	0	19.2	36.8	52.8	67.2	80	91.2	100.8	108.8	115.2	120	123.2
6	0	18.4	35.2	50.4	64	76	86.4	95.2	102.4	108	112	114.4
7	0	17.6	33.6	48	60.8	72	81.6	89.6	96	100.8	104	105.6
8	0	16.8	32	45.6	57.6	68	76.8	84	89.6	93.6	96	96.8
9	0	16	30.4	43.2	54.4	64	72	78.4	83.2	86.4	88	88
10	0	15.2	28.8	40.8	51.2	60	67.2	72.8	76.8	79.2	80	79.2
11	0	14.4	27.2	38.4	48	56	62.4	67.2	70.4	72	72	70.4
12	0	13.6	25.6	36	44.8	52	57.6	61.6	64	64.8	64	61.6
13	0	12.8	24	33.6	41.6	48	52.8	56	57.6	57.6	56	52.8
14	0	12	22.4	31.2	38.4	44	48	50.4	51.2	50.4	48	44
15	0	11.2	20.8	28.8	35.2	40	43.2	44.8	44.8	43.2	40	35.2
16	0	10.4	19.2	26.4	32	36	38.4	39.2	38.4	36	32	26.4
17	0	9.6	17.6	24	28.8	32	33.6	33.6	32	28.8	24	17.6
18	0	8.8	16	21.6	25.6	28	28.8	28	25.6	21.6	16	8.8
19	0	8	14.4	19.2	22.4	24	24	22.4	19.2	14.4	8	0
20	0	7.2	12.8	16.8	19.2	20	19.2	16.8	12.8	7.2	0	0
21	0	6.4	11.2	14.4	16	16	14.4	11.2	6.4	0	0	0
22	0	5.6	9.6	12	12.8	12	9.6	5.6	0	0	0	0
23	0	4.8	8	9.6	9.6	8	4.8	0	0	0	0	0
24	0	4	6.4	7.2	6.4	4	0	0	0	0	0	0
25	0	3.2	4.8	4.8	3.2	0	0	0	0	0	0	0
26	0	2.4	3.2	2.4	0	0	0	0	0	0	0	0
27	0	1.6	1.6	0	0	0	0	0	0	0	0	0
28	0	0.8	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0

General Instructions (License Policy Treatment)

General Information: The purpose of this experiment is to study how people make decisions in an environment in which there is a shared resource that may be competitively produced while also be produced in a way that benefits all. From now and until the end of the experiment any verbal or written communications with other participants is not permitted. If you have a question, please wait until all instructions have been read. If you have a question after the instructions have been read, please raise your hand and the experimenter will be with you as soon as available.

You will receive $7.00 for showing up on time for the experiment. In addition, you will have an opportunity to earn more money during the experiment. All currency in this experiment will be denominated in Experimental Currency Units (ECU's). At the end of the experiment, those ECU's will be translated into U.S. currency at the rate of 100 (ECUs)= $1.00. At the end of the experiment you will be paid, in cash, the sum of your show-up fee and earnings from the experiment. You will be paid privately and we will not disclose any identifiable information about your decisions or payment to other participants in the experiment. For ease of payment, all earnings will be rounded up to the nearest quarter to keep loose change to a minimum.

Groups and Rounds:

Today, you will be placed into groups with 3 other participants. The decisions of the groups are completely independent in each round. That is to say, nothing Group 1 does will affect the other groups at any point of the experiment, and vice versa.

Today's experiment will consist of 20 independent "rounds", each lasting no longer than 3 minutes. Each round you will be placed into a random group with 3 other participants. These rounds are the screens where you will be making decisions that will be described in the next section. Once again, independent here means that any decision made in one round will not affect what happens in any other round. You will not be able to see the individual decisions of your fellow group members, however at the end of each round you will see the overall outcome for your group, as well as your earnings from that specific round.

At the end of the experiment, after the 20th round you will see a payoff screen that tells you how many ECU's you have earned from each round, and what your final total payoff is in U.S. currency.

Description of Decisions, Accounts, and Payoffs:

Decisions:

In each round, you and your group will be tasked with making investment decisions in three different accounts: a production account, a public account, and a private account.

Each of you will be given an endowment of 11 tokens for each round to use as a budget. These tokens are what you will use to invest in each of the three accounts. When you invest your tokens, the computer will tally up your and your group members' investments and convert your tokens into an ECU payment. You cannot exceed this budget. If you attempt to invest more than 11 tokens, the computer will give you a message box reminding you of this constraint.

Production Account:

The production account is an account where you and your group may invest your tokens to produce a pile of ECUs, that will be split amongst you and your group according to how much you invested relative to the rest of your group. Mathematically, the return on this account is equal to:

$$ECUs = \frac{(Your\, investment)}{(Group\, investment)}[14 * (Group\, investment) - 0.5 * (Group\, investment)^2]$$

The return on investment from the production account is also described in Table 2. The columns of table 2 show your return for the production account based on how many tokens you invest, while the rows show your return based on how many tokens the rest of your group invests. For example, column 3 row 9 shows you how much you would earn from this account if you invest 3 tokens and the other 3 members of your group invest a total of 9 tokens to the production account.

Public Account: The public account is an account where you and your group may invest your tokens to produce ECUs for the entire group. Each token invested in the public account increase everyone's earnings by 2 ECUs. Mathematically this is equivalent to:

$$ECUs = 2 * Total\, token\, balance$$

Private Account:

The private account is an account where you can save any tokens you would not like to invest in either the production account or public account. As the name suggests, the private account is entirely private, therefore any token you save will go towards your earnings alone. Each token that is saved in the private account will be converted into 4 ECUs at the end of the round. So, if I were to save 5 of my 11 tokens, then I would earn 20 ECUs from the private account at the end of the round. You do not actively place tokens in the private account. From your budget of 11 tokens, your private account savings are simply determined to be however many of the 11 tokens you have not placed in either the production or public accounts. As an example, suppose I invest 4 tokens in the production account, and invest 2 tokens towards the public account. My private account savings would then be calculated based on my leftover tokens, i.e. the 4 tokens I have not invested or invested. Because any token invested or invested into the production or public accounts is automatically placed in the private account, if you choose to not invest or invest any tokens, your entire endowment will automatically be saved in the private account. Similarly, if you do not submit your investment decisions within the 3-minute time period, your entire endowment will be placed in the private account as well. Even if you have typed some investment decisions into the account boxes, if you do not hit the submit button in the lower right corner of the screen, your entire endowment will go to the private account.

Account Spillovers:

In each round, there will be spillovers between the production and public accounts based on your investment decisions. These spillovers are triggered if and only if your group's investment decisions in either account exceed a certain threshold. These spillovers are effects from one account that affects another, i.e., production account influencing the public account and vice versa.

Production spillovers:

If your group's token investment in the production account exceeds a total of 14 tokens, then any additional token invested in the production account will reduce the public account balance by 1 token. For example, suppose my group's investment in the production account is 15 tokens in a round when the production spillover is in effect. With the threshold of 14 tokens, that means the 15th token that is spent, reduces the balance of tokens we've invested to the public account by 1. Keep in mind, this also means that the public account can turn negative depending on how much you invest in the production and public accounts.

Public spillovers:

If your group's public account balance is at least 14 tokens, then the production account will become more productive.

The new production function that is applied when this spillover is triggered is:

$$ECUs = \frac{(Your\, investment)}{(Group\, investment)} * [24 * (Group\, investment) - 0.8 * (Group\, investment)^2]$$

The return on your investment on this more productive account can be found in Table 3. This table can be read in the same way as table 2. As you can see in table 3, each cell has a higher payoff than the corresponding cell from table 2.

Keep in mind how these spillovers are defined. While the public account spillover makes the production account more productive, the production account spillover reduces how many tokens are in the public account. This means that for every token invested in the production account beyond the threshold of 14, you will need an additional token invested in the public account to trigger the public account spillover.

An example of this, suppose my group has chosen to invest exactly 14 tokens in the public account and 15 tokens in the production account. Because we exceeded the production account threshold by 1 token, this means the tokens in the public account decrease by 1, due to the spillover from the production account. This means we will need yet another additional token invested to the public account in order to trigger the public account's spillover.

Production Account Licenses:

For rounds 1-10 today only, two people in each group will receive licenses for the production account. These licenses determine whether or not you may invest in the production account. If you are not one of these two group members that have a license, for rounds 1-10 you will not be allowed to invest in or earn ECUs from the production account. You will know you did not receive a license if the production account box does not appear on your computer screen for rounds 1 through 10.

The two members that do receive licenses for the production account will have the exclusive ability to invest in and earn ECUs from the production account. However, these licenses also have an investment cap. Each of the members with a production account license cannot invest more than 7 of their own tokens in the production account per round

There will be no difference to the private account or the public account in rounds 1 through 10 today. The production account licenses only apply to investment in the production account, and do not place any limits on the other two accounts. Subject to your constraint of 11 tokens, you may invest however many tokens you wish in the public account or private account, regardless of whether or not you have one of the licenses.[10]

[10]Tables 2 and 3 from the previous set of instructions are also included in this set of instructions, and are no different. I have omitted including them a second time in this instruction set for Appendix D to save space.