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RESEARCH ARTICLE

Externalities and common pool licenses: An experimental study of managing differing natural resource uses

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Abstract

In this paper, I discuss dual collective action problems in which a resource pool has simultaneous common pool and public good aspects in its usage, such as hunting (consumption) and conservation of wildlife. I then implement laboratory experiments to evaluate how spillovers between the two related uses of nature affect the consumption and conservation habits of stakeholders. The Nash predictions suggest that even the most selfish of profit-maximizing agents have an incentive to provide equally towards resource consumption and conservation when resource spillovers are present. Results from laboratory experiments are consistent with this hypothesis. As a policy intervention, I introduced and later revoked 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.

Keywords: Common pool resources; experimental economics; natural resources; public goods

JEL codes: C92; H41; Q50; Q56; Q57

Introduction

Natural resource managers and stakeholders must balance consumption and conservation to address collective action problems in the use of the environment. The differing preferences towards resource uses are often classified as either *domination-oriented* preferences (hunting, fishing, extraction) or *mutualist-oriented* preferences (wildlife spotting, education, conservation).[1]

Consider, for instance, gray wolves (*Canis lupus*) in Yellowstone National Park and the surrounding lands. Historically, the gray wolf had significant value as a hunting resource

[1]These classifications are derived from a 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).

for their pelts.[2] At the same time, the presence and conservation of wolves have value as a public good to 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 coyote population and other predatory species that can be more destructive to wildlife when their populations go unmanaged. By 1926, the gray wolf population in Yellowstone National Park had been extirpated by years of overhunting.

Following the decline of the wolf population below the sustainable population level, the local elk population boomed, drastically harming the forest growth of Yellowstone and reducing 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. 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 et al. 2013). The regions surrounding Yellowstone perfectly illustrate this multidimensional idea of a resource pool that has value through investing in productive extraction and preservation. Moreover, the history of hunting and conservation in the Yellowstone area represents significant spillovers between consumption and conservation practices.

In the following model and laboratory experiment, I produce a combined game consisting of separate resource accounts: a common pool resource (CPR) Investment game and a linear public good (PG). I then impose account spillovers motivated by the externalities from the history of Yellowstone. The account spillovers are employed to understand how shocks to environmental sustainability can impact investment decisions in both uses of nature. Theoretical and empirical results suggest that these spillovers exasperate the social dilemmas from the common pool and public good accounts. In response, I also employ a licensing policy treatment modeled after Florida fish and wildlife policies that provide restrictive licenses via lottery to a select few stakeholders. Theory predicts that the common pool's social dilemma is mitigated. However, the public good social dilemma is worsened. Because some stakeholders are barred from participating in the CPR process, they are not as incentivized to provide for the public good as they do not experience the external benefits that license holders experience from sufficient conservation of the public good.

This work expands upon previous works concerned with two related collective action problems, between common pool resources and public good provision. Similar resource environments have been explored to explain asymmetric common pool dilemmas that result from an initial public good provision (Janssen et al. 2011; Cason and Gangadharan 2015; De Geest et al. 2017; Chávez et al. 2018; Jarke-Neuert 2023). A natural resource or its infrastructure, such as water infrastructure for irrigation, may need to be provided before stakeholders can invest in CPR production. In this paper, I explore a related social-ecological system in which environmental provision coincides with stakeholders' extraction choice.

A fundamental issue in common pool resource dilemmas is the stakeholders' profit incentive to overproduce from the common pool. While game theoretic predictions often suggest frequent overuse 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 deterioration of the environment, whether as the result of experimental treatment or the endogenous formation of institutions in the lab (Walker et al. 1990; Walker and Gardner 1992; Ostrom, Walker, and Gardner 1992; Cardenas, Stranlund, and Willis 2000; Wilson et al. 2012).

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

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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 this article's primary motivation is 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.

Consumption and conservation game

Baseline game and resource account spillovers

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). Any tokens not invested in the two resource accounts are automatically saved in a private account with a fixed rate of return $w > 0$.

The production account follows the typical constituent game Ostrom, Walker, and Gardner (1992) produced. 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 the group's total investment. Specifically, using the Ostrom, Gardner, and Walker (1992) parameterization, the individual return on the production account is equal to

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

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.

The public account follows the standard design for a linear public good, with a marginal per capita return $c > 0$. A linear public good illustrates the vertically additive nature of environmental quality and biodiversity to consumers. Unlike most competitive rivalrous markets, the value of environmental quality is not determined by the individual with the highest value or willingness to pay but rather by the sum of values all stakeholders have over it, defined in the model as $\sum d_j$.

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

$$\pi_i = w(e - x_i - d_i) + \frac{x_i}{\sum x_j} F\left(\sum x_j\right) + c \sum d_j \tag{3}$$

Assume furthermore that $a > w > c$.[3] The marginal returns over all three accounts are calibrated in such a way as to capture the essence of how resource stakeholders engage with the environment. Stakeholders would not invest in the production of a CPR if an outside

[3]This choice of parameters is to ensure an interior solution to the combined CPR and PG game. Reordering this inequality will result in a boundary solution where agents only invest or donate some of their endowment, but not both.

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alternative were strictly more beneficial. Additionally, donating towards the public good has little individual return but greater benefits to the group.

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

$$x^* = \frac{a-w}{b(n+1)} \tag{4}$$

and

$$d^* = 0 \tag{5}$$

This Nash Equilibrium exists on the decreasing marginal return side of the quadratic production function. This means that we would expect profit-maximizing agents to marginally over-invest in producing from the resource pool to the point where any additional token invested 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 donations towards the public good aspect of the resource pool. Therefore, any token not invested in the CPR would be automatically saved in a decision-maker's private account.

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. Like the competitive symmetric equilibrium, the social optimum derived from this social planner's problem draws from the common pool literature and public good literature. The social optimum individual investment and donation produced from the planner's problem is given by:

$$x^{so} = \frac{a-w}{2nb} \tag{6}$$

and

$$d^{so} = e - x^{so} \tag{7}$$

This result illustrates that 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 donate whatever else remains of their endowment into the public good account. Conditions for the existence of this social optimum are provided in Appendix D. The key result of the symmetric Nash Equilibrium and the socially optimal outcome 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 $x^{so} < x^*$ 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 overhunting of wolves led to a massive boom in elk populations that decimated forest growth with over-grazing. After a public effort to reintroduce wolves in the mid to late 1990s, 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, overhunting harming public value, conservation benefiting the common pool, and wildlife diversity benefiting recreational

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game hunters. To implement environmental externalities in my game theoretical model, I introduce two account spillovers defined by the thresholds τ_c and τ_p for common pool investment 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 $\left(\sum x_j - \tau_c\right)$ tokens.
2. Public Good Externality: If $\sum d_j \geq \tau_p$, then the production account return becomes $F_h\left(\sum x_j\right) = [a_h \sum x_j - b_h(\sum x_j)^2]$, where $a_H > a$ and $b_H < b$.

For the model's simplicity, I impose the constraint that $\tau_c = \tau_p = \tau$, i.e., the externality thresholds are homogeneous.[4] 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. Therefore, the interpretation of the maximum sustainable yield in this model is twofold. First, it represents where further investment in common pool production has a negative marginal return. Secondly, including resource account spillovers represents the point for which over-investment in common pool production reduces environmental quality for stakeholders in the resource pool.

An essential detail of the account spillovers is that they can interact by how 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. Without public account donations, this would make the public account negative and make the public good into a "public bad." Because of how the public good externality works, if the common pool externality is in effect, it will also take proportionally more donations to have it levied. For every token over-invested in the production account (beyond τ), the public account balance will decrease by one token, which will take an additional token to reach the public account externality threshold. This scenario mimics how overhunting 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 directly invested in. As this is the case, two feasible Nash Equilibria exist in the presence of resource account spillovers. The symmetric Nash Equilibrium for the baseline game provided in equations (5) and (6) persists, even with resource account spillovers. However, a second equilibrium is added if the agents' endowments are sufficiently large, i.e., $n * e2\tau$, and agents can coordinate on sufficiently donating towards the linear public good. If such is the case, there is a Nash Equilibrium in which there is over-investment in the CPR relative to the socially optimal level, and the public account receives sufficient donations meeting the social optimum. We have that

$$x_j^* = \frac{a_H - w}{b_H(n+1)} \tag{8}$$

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

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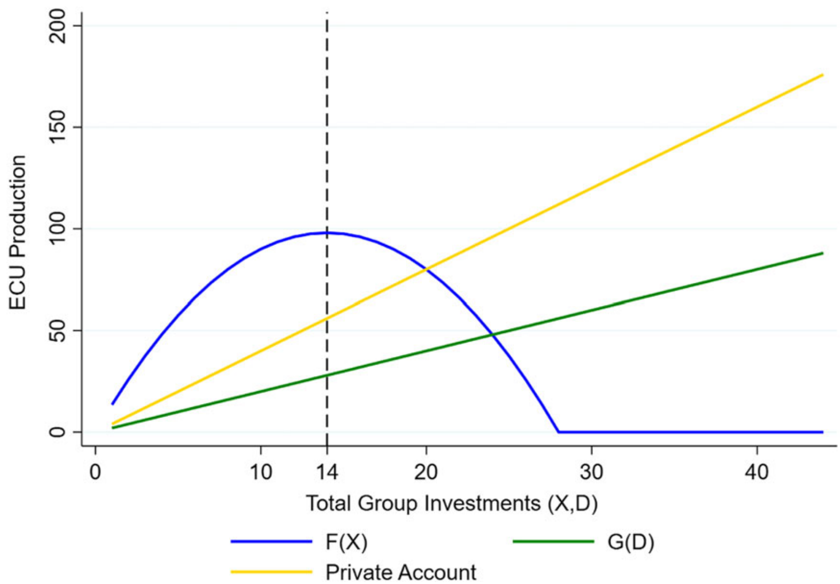

Figure 1. Baseline game group production functions.

$$d_j^* = x_j^* \tag{9}$$

Because the resource spillovers share a common threshold, the only way public good donations can yield a positive spillover is if donations match the level of investment.

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 quadratic production function parameterized earlier in this section. However, Figure 2 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. In contrast, over-investment in the common pool resource beyond the threshold will result in deductions in the balance of the public good. This visually illustrates how the proposed externalities encapsulate how conservation improves productivity in the common pool and how over-investment reduces the benefits of donations.

The social optimum level of investment and donation towards the resource pool follows an expression similar to those found in the game without resource spillovers. For the game with spillovers, the socially optimal levels of investment and donation are given by:

$$x^{so} = \frac{a_H - w}{2nb_H} \tag{10}$$

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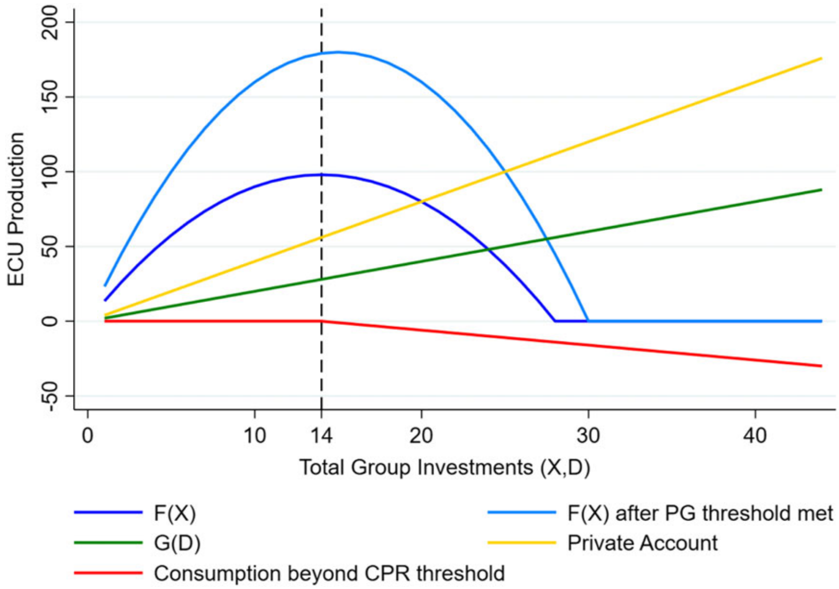

Figure 2. Group production functions with spillovers.

$$d^{so} = e - x^{so} \tag{11}$$

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 in the higher yield production function. This results in more investment in the CPR relative to the game without spillovers and less investment in the public good but a greater return for the group with the spillovers in effect.

Because two symmetric Nash Equilibria are in the game with spillovers, there is a coordination problem between the resource stakeholders on their preferred level of public good donation. If the decision-makers can coordinate sufficient donations towards the public good, their group will approach the payoff dominant symmetric Nash Equilibrium in which they balance their spending equally across the CPR and public good. This, however, requires that the group efficiently coordinate their public good investment. If any one agent is anticipated to defect and free ride on a public good investment, the payoff dominant symmetric Nash Equilibrium will be unattainable. This coordination problem could potentially exacerbate 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. Still, 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 in the public good.

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"Optimal" licensing of the commons

Consider the combined CPR and PG game with spillovers again. However, now, suppose that a central planner wishes to mitigate this environment's social dilemma by instituting CPR investment licenses through a lottery.[5] 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 a lottery determines permit allocation after the application window closes each year. Permits often allow hunting animals, like alligators and antler-less deer, that may be susceptible to overhunting without licenses (Florida Fishing and Wildlife Conservation Commission n.d.).

In addition to quotas on resource extraction, several capped permits in Florida's fishing and wildlife policy encompass restrictions on "extraction methods." For example, some licenses restrict muzzle-loading firearms used in hunting, bow hunting, and airboat usage. Restrictions on hunting and fishing methods represent a mechanism by which central planners may restrict how effort is invested in resource pool production in addition to extraction quotas (Lueck, 2018).

For a CPR investment licensing policy to be optimal from the perspective of reducing the social dilemma in CPR investment, 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 costly, as it would require the regulatory agency to know the productivity of all hunters engaging with the resource. However, state agencies, such as the Florida Fish and Wildlife Conservation Commission, have historically determined a sustainable population to harvest and restrict access and levies quotas to meet that sustainable yield. While not the first-best policy, the clear advantage of a consumption license capping investment at the maximum sustainable yield almost entirely avoids the costs of measuring output. While such a policy does not guarantee the elimination of the CPR social dilemma, as $x^{so} \leq x^{msy}$, the cap would place an upper bound on the competitive equilibrium between the resource stakeholders left with licenses. For those who are allocated a capped CPR investment license, this would translate to

$$x^{so} \leq x_L^* \leq x^{msy}$$

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.

In the designed model and accompanying experiment, I parameterize the licensing policy to assign half the stakeholders within a group a CPR investment cap license for the same combined game with spillovers. This means that only $\frac{n}{2}$ agents receive an investment license with an investment cap set at the maximum sustainable yield (MSY) for the common pool and can 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.

[5]An assumption of this model and the licensing policy described in this section is that the hunting context of this work only considers commercially valuable hunts and thus may severely limit the interpretation of the license policy treatment results. In the field, it is common for licensed hunters to act upon other economic incentives, such as utility maximization from participating in an enjoyable activity.

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Reducing CPR access does introduce a "fairness" problem among 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 if there are sufficient donations towards the public good. 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 efforts. 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 a positive spillover from the public good. We obtain improved biodiversity and environmental quality from conservation efforts, and those who often benefit the most from the accompanying spillovers are those who invest in the resource pool's production. Those excluded from CPR access (those without a license) may find it unfair that their donations towards the public good create an external benefit for others.

While "fairness" is a concept more applicable to a behavioral model, there is something concrete to be said about social dilemmas when facing the proposed policy within 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 can no longer reap the spillover benefits of PG investment, the symmetric Nash Equilibrium for them is reduced to

$$x^*_{nL} = d^*_{nL} = 0 \tag{12}$$

Since they cannot invest in the CPR without a license, saving the entirety of their endowment yields each individual the highest marginal return. For those that obtain a capped CPR investment license, their symmetric Nash Equilibrium for the combined game with spillovers becomes

$$x^*_L = \frac{a - w}{b\left(\frac{n}{2} + 1\right)} \tag{13}$$

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

$$d^*_L = 0 \tag{14}$$

assuming that endowments and group size are such, 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

$$x^{so} \leq x^*_L \leq x^{msy}$$

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 now have a weaker incentive to invest in the public good. The socially optimal level of investment in the CPR and PG does 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). Public good donations are nonzero for the game with spillovers and without the policy, albeit 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 unfunded at the competitive equilibrium. Such a policy would only be beneficial if the over-investment in the common pool is greater than or equal to the increase in donations to the public good. This cannot be the case in theory, however, as it would require:

$$x_L^* > x^*$$

, 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 reduce the symmetric equilibrium investment level.

In summary, an investment-capped license lottery policy would 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 this policy are always less than or equal to zero.[6] This means that no optimal policy for the combined CPR and PG game with spillovers would bar stakeholders' access to common pool investment when agents are strategic profit-maximizing decision-makers.

Experimental methodology & hypotheses

Two questions from this model motivate the hypotheses of this study.

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?

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 will use the constructed laboratory experiment that simulates the game with spillovers and will vary the modeled CPR investment licensing policy as a within-subjects treatment.

Table 1 provides parameterizations for the game-theoretic environment. The 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 $100 ECUs = \$1.00$ for the spillover treatment sessions and $180 ECUs = \$1.00$ for the licensing policy treatment sessions.[7] All other parameterizations of the game environment for the experiment follow the assumptions in designing the model discussed in Section 2.

This experiment was programed and tested over zTree (Fischbacher, 2007) at Florida State University's XS/FS experimental computer lab. Subjects were recruited over the XS/

[6]This proof is given in Appendix D.

[7]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 without a scale adjustment.

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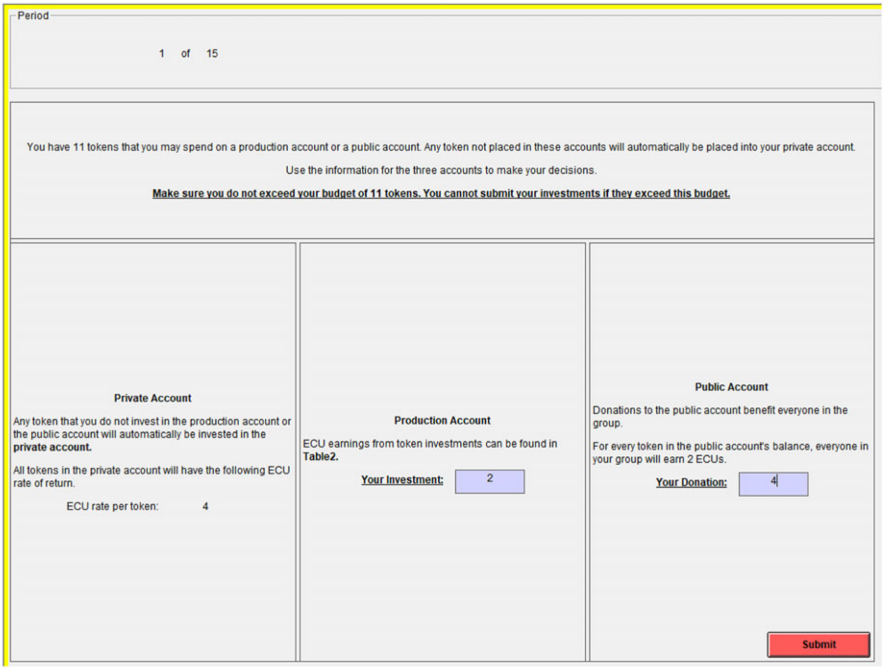

Figure 3. zTree interface.

FS group's undergraduate experimental participants recruitment list. This list draws from a pool of undergraduate students who have chosen to participate in the XS/FS group's laboratory research.

Images of the computer interface subjects interacted with are provided in Figures 3 and 4. In the experiment, and as seen in the user interface images, subjects were randomly sorted into anonymous groups of four who could not formally communicate. Each group was informed that they would play 15 games and remain in the same group for each game. Each game was explained to be independent of 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 a single group in any period would not affect 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 three accounts: a production account (CPR), a public account (linear PG), or a private account. The investment returns in the three accounts were provided to them in the instruction handout at the beginning of the experiment.[8]

The production account was explained to subjects as an account where their group could invest to produce a pile of ECUs, and their return on that production would be distributed by how many tokens they individually invested in that account, proportional to

[8]After instructions were read, all participating subjects were quizzed on their comprehension of the decision tasks. The experimental session could not continue until all present had answered every question correctly. The questions asked of subjects are provided in Appendix C.

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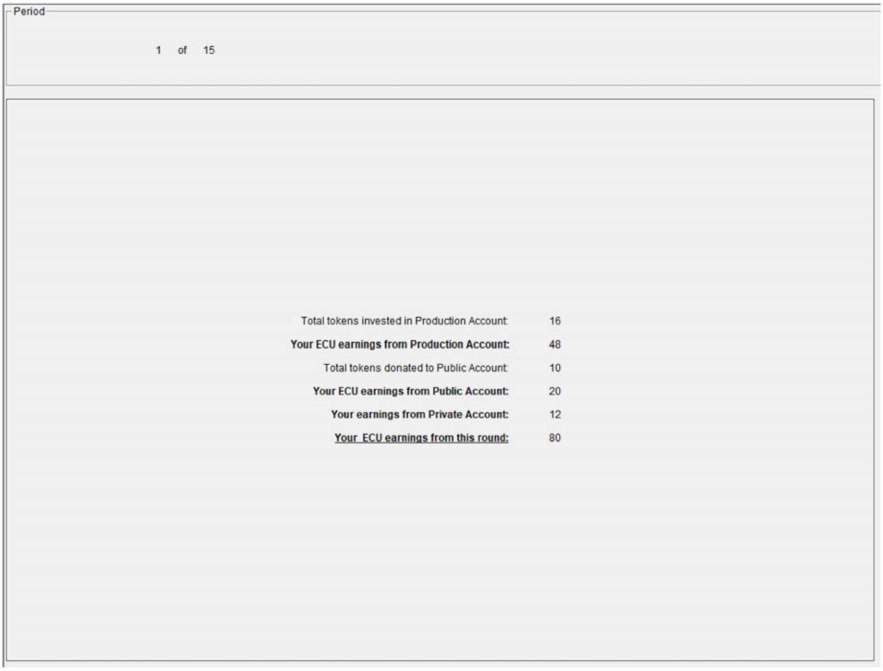

Figure 4. End of game information screen.

the rest of the group's investment. The payoff function on the production account was provided to the subjects as a function and in table form. The precise details of this function are provided in Table 1, and the payoff table on the production account can be found in the sample instructions provided in Appendix E. As the subjects were informed, the public account 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 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 privately visible on a "payoff screen" to each subject. Additionally, on this payoff screen, subjects could see how many total tokens from their group were invested in either the production or public accounts. This was done to improve efficient group coordination on investment decisions. Without 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 for their earnings during the experiment.

For some 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

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Table 1. Experiment parameterization

Experiment characteristics	No spillovers (baseline)	Account spillovers (externality treatment)	Licensing policy (licensed subjects)	Licensing policy (unlicensed subjects)
Group Size	4	4	4	4
CPR and PG Token Threshold	–	14	14	14
Individual Token Endowment	11	11	11	11
CPR Production	$F(\sum x) = 14\sum x - 0.5(\sum x)^2$	$F(\sum x) = 14\sum x - 0.5(\sum x)^2$	$F(\sum x) = 14\sum x - 0.5(\sum x)^2$	–
CPR Production				
(PG threshold met)	–	$F_h(\sum x) = 24\sum x - 0.8(\sum x)^2$	$F_h(\sum x) = 24\sum x - 0.8(\sum x)^2$	–
PG Production	$G(\sum d) = 2\sum d$	$G(\sum d) = 2\sum d$	$G(\sum d) = 2\sum d$	$G(\sum d) = 2\sum d$
PG Production				
(CPR Threshold Exceeded)	–	$G(\sum d) = 2(\sum d - \sum x + 14)$	$G(\sum d) = 2(\sum d - \sum x + 14)$	$G(\sum d) = 2(\sum d - \sum x + 14)$
Private Account Marginal Return	4	4	4	4
Dominant Nash EQ CPR Investment	4	5	6.67	0
Dominant Nash EQ PG Investment	0	5	0	0
Social Optimum CPR Investment	2.5	3.125	6.25	0
Social Optimum PG Investment	8.5	7.875	4.75	11

14 tokens in the public account would cause the production account to become "more productive." A new function and table gave a more productive return on the production account at the end of the instructions. In each laboratory session, the subjects were asked how this new production function on the production account was more "productive" than if the public account threshold was not met. This is 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 the corresponding cells of the last table.

I ran two treatment sequences to evaluate the effects of the resource account spillovers on CPR and PG investment. The first sequence had subjects play the baseline game with no spillovers (NS) for the first five games, the game with spillovers for games six through ten (S), and the baseline game without spillovers for the final five games (NS). Using this NS/S/NS design, henceforth 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 experiment period.

A new sequence of sessions was run with the modeled CPR license lottery system, which was used as an experimental treatment to evaluate the investment cap license policy in this experimental environment. A new sequential strategy was followed for the policy treatment sessions. Each group of subjects played 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 ten games with the licensing policy and the final ten without.

For the first ten 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 who received a license would keep and retain that permit for the entire 10-game sequence. The licenses the two group members would receive would include an investment cap on the production account. License-holding subjects could not invest more than seven tokens in the production account.[9] Those without a license could not invest in the production account for the block of ten games. Non-permitted subjects would know this, as the production account would disappear entirely from their screen during the ten-game block. The only public and private accounts available to them on their computer screen.

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 intervention.

It is not necessarily the interest of this experiment to address within subjects how implementing this license policy would impact consumption and conservation. The reason *implementing* the policy is of little interest is that all 50 states already have license lottery systems for selected hunting and fishing permits. Though licensing policy may differ in

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

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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

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 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 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 increase public good provision between blocks of games where the combined CPR and PG game is played with and without resource account spillovers.

H2. (Spillover Effect - CPR)

The presence of resource account spillovers will increase common pool investment between blocks of games with and without resource account spillovers.

H3. (Licensing)

The rescinding of a licensing policy of capped investment for the common pool will increase the common pool and public good investment.

The first two hypotheses are derived from the symmetric Nash predictions for the combined game and the first motivating question. The competitive equilibrium predicts no public good provision without 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, 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 toward 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

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public good is between zero and five tokens per subject. Therefore, the CPR spillover effect is anticipated to be much weaker.

Hypothesis 3 is derived similarly from the second motivating question and the new Nash predictions under the licensing policy treatment. With a capped licensing policy where only half of the resource stakeholders are allocated an allowance for CPR investment, we would anticipate lower CPR investment. This effect comes from decreased 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.

In my experimental parameterization, my model would predict that in a competitive symmetric Nash equilibrium, subjects will invest four tokens in the CPR and donate nothing to the PG without any spillovers between the resource accounts. This would mean that I would expect the CPR to be over-produced and the PG to be underfunded relative to the social optimum of investing 2.5 tokens in the CPR and 8.5 tokens in the PG. When spillovers are present, I still predict the same social dilemmas as before; however, with the ability to support greater production from the CPR with sufficient PG donations, it is predicted that for the payoff dominant symmetric Nash Equilibrium, the incentive for subjects to free ride on the public good is diminished. The payoff dominant NE predicts that subjects will equally invest and donate five tokens to the CPR and PG, respectively, leaving one token for themselves in their private account. The socially optimal outcome is for individuals to invest approximately 3.125 tokens into the CPR and 7.875 in the PG.

In the face of a license policy that restricts access to the CPR aspect of the resource pool, it is predicted that subjects with a CPR license will invest approximately 6.67 tokens in the CPR while free-riding on the public good. Relative to the socially optimal level of investment in the CPR, little over-production is predicted as the socially optimal level of investment is 6.26. Subjects who are not allocated a license are predicted to keep the entirety of their endowment in their private account. At the same time, the socially optimal outcome would prescribe them to donate their endowment to the public good.

Results

A total of 52 undergraduate subjects from Florida State University participated in the 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 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 NS/S/SN spillover treatment sequence, and six 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 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 before the spillover treatment is enacted in the sixth game. Once the spillover treatment is

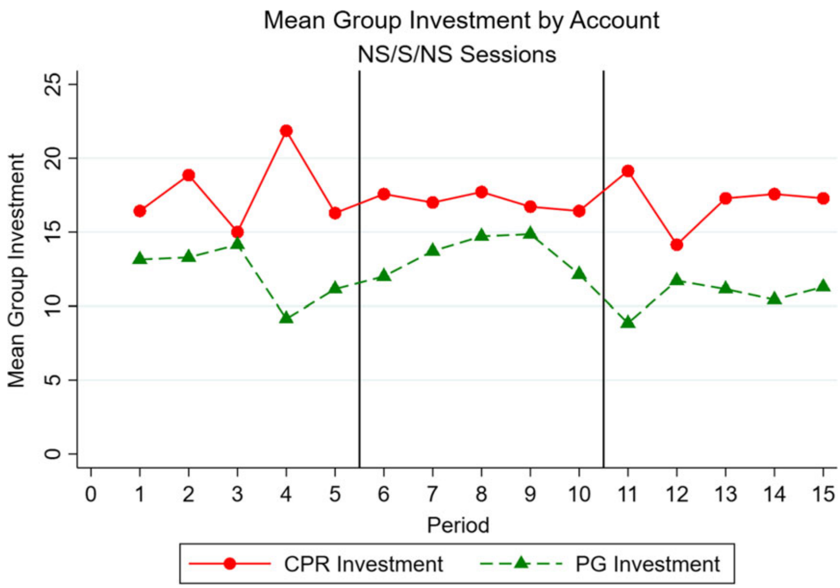

Figure 5. Group means NS/S/NS sessions.

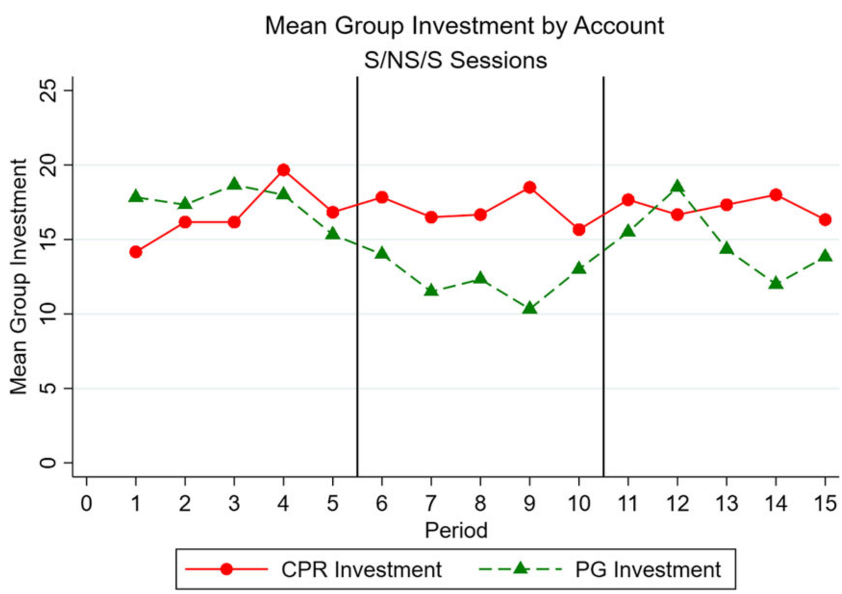

Figure 6. Group means S/NS/S sessions.

enacted, public good provision gradually increases as the subjects learn that the positive PG spillover benefits CPR investment. This increase from the spillover treatment gradually disappears like "endgame trends" shown in the linear public goods experimental literature

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Table 3. Sign rank test for treatment effect on public good donations (NS/S/NS sessions)

Games 1–10	Obs	Sum ranks	Expected	Games 5–15	Obs	Sum ranks	Expected
Positive	10	150.5	201.5	Positive	14	249.5	198
Negative	16	252.5	201.5	Negative	10	146.5	10
Zero	2	3	3	Zero	4	10	10
	Z Score −1.162				Z Score 1.175		

Table 4. Sign rank test for treatment effect on public good donations (S/NS/S sessions)

Games 1–10	Obs	Sum ranks	Expected	Games 5–15	Obs	Sum ranks	Expected
Positive	19	259.5	150	Positive	9	95.5	148.5
Negative	5	40.5	150	Negative	13	201.5	148.5
Zero	4	10	10	Zero	2	3	3
	Z Score 3.130***				*Z* Score −1.515		

in the past. Following the tenth game, the spillover treatment disappears, and we can see public good provisions return to a reduced level; however, they are 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 decreases. 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 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 reached; however, for four of the ten games played will account for spillovers in this treatment sequence, it is observed that public good provision was more than common pool investment.

Tables 3 and 4 examine the treatment effect of the resource account spillovers when evaluating within subjects. The two tables provide the results of two Wilcoxon signed-rank tests. Due to the lack of independence of subject choices between periods, the signed-rank test provides a non-parametric estimation of the sign of the treatment effect between treatment conditions for each subject. Each panel represents a signed-rank test between two treatment conditions. While lacking statistical power, the conducted tests demonstrate that, on average, subjects donated relatively more of their endowment to the public good when the resource spillovers were present relative to when there were no spillovers.

For between-subjects analysis, Wilcoxon rank-sum tests are provided in Table 5 that compare subject donations to the public good for each treatment condition. Using the reverse order treatment sequence, each block of five games in the experiment from one sequence directly compares to the separate treatment condition from the opposite sequence. For example, in the S/NS/S treatment sequence, the subjects experienced spillovers for the first five games of the session, while in the NS/S/NS sequence, subjects

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Table 5. Sum rank test for treatment effect on public good donations between subjects

	Obs	Rank sum	Expected	*Z* score
NS/S/NS Games 1–5	28	621	742	2.24**
S/NS/S Games 1–5	24	757	636	
NS/S/NS Games 6–10	28	793	742	−0.937
S/NS/S Games 6–10	24	585	636	
NS/S/NS Games 11–15	28	736.5	742	1.846*
S/NS/S Games 11–15	24	651.5	636	

experienced no spillovers. The results of these tests provide more powerful evidence of subjects increasing their public good donations in the face of resource spillovers.

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 the current game level of individual investment. I included the spillover treatment effect while implementing session-period fixed effects. Table 6 provides the results of my specifications. The outcome variables in both columns are the current game's level of individual CPR investment or public good donation. The lagged regressors are group-level investments in the PG and CPR, respectively, and the length of time the previous game took to complete for the group. The lagged variables constitute information that each subject saw between games, regardless of session sequence. Each subject, between games played, would always see how many tokens their group invested in the CPR and how much their group invested in the PG account. I find little correlation between the lagged independent variables and the treatment indicator.

The fixed effects analysis results suggest no observable difference between CPR investment and whether account spillovers are present. On the other hand, spillovers increased public good donations by approximately 1.68 tokens relative to the baseline games played. This treatment effect is significant at the 10% level, so I fail to reject the null hypothesis that no treatment effect exists. These regressions and their specifications provide evidence that supports Hypothesis 1 but fails to support Hypothesis 2.

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 literature, 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 close to the symmetric Nash prediction of 16 total tokens per group. Like much of the experimental literature surrounding linear public goods, I do not observe either the Nash prediction of zero investment or 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 significantly increases and approaches the group-level CPR investment. On average, the difference between CPR investment and public good provision with spillovers is still positive. This means that the CPR remains over-invested relative to the public good. In addition, this result also means that, on average, groups could not trigger the positive spillover from sufficient public good

Table 6. Treatment effect on account spending (FE OLS)

	CPR Investment			PG Donations		
	(1)	(2)	(3)	(4)	(5)	(6)
Spillover Indicator	–0.177 (0.126)	–0.185 (0.127)	1.488 (1.085)	0.747*** (0.198)	0.802*** (0.169)	1.680* (0.916)
CPR Lag	–	–0.021 (0.022)	0.006 (0.033)	–	0.073*** (0.020)	0.093*** (0.027)
PG Lag	–	–0.003 (0.007)	0.011 (0.099)	–	0.053*** (0.011)	0.055*** (0.018)
Time Lag	–	0.009 (0.007)	0.010 (0.005)	–	–0.003 (0.004)	–0.001 (0.005)
Time Lag × Spillover	–	–	–0.007 (0.004)	–	–	–0.004* (0.002)
CPR Lag × Spillover	–	–	–0.063 (0.052)	–	–	–0.043 (0.032)
PG Lag × Spillover	–	–	–0.026 (0.015)	–	–	–0.006 (0.017)
Constant	3.848*** (0.22)	4.218*** (0.488)	3.470*** (0.547)	3.362*** (0.349)	1.068 (0.681	0.723 (0.890)
Period Fixed Effects	Y	Y	Y	Y	Y	Y
Session Fixed Effects	Y	Y	Y	Y	Y	Y
Obs	780	599	599	780	599	599
R^2	0.020	0.028	0.034	0.067	0.097	0.100

Reported standard errors are clustered at the group level.

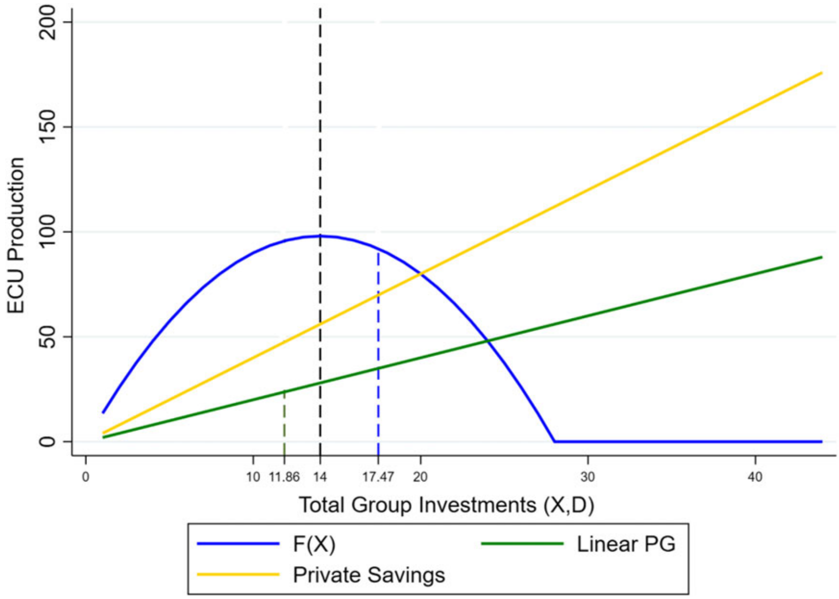

Figure 7. Baseline group production functions with group mean investments.

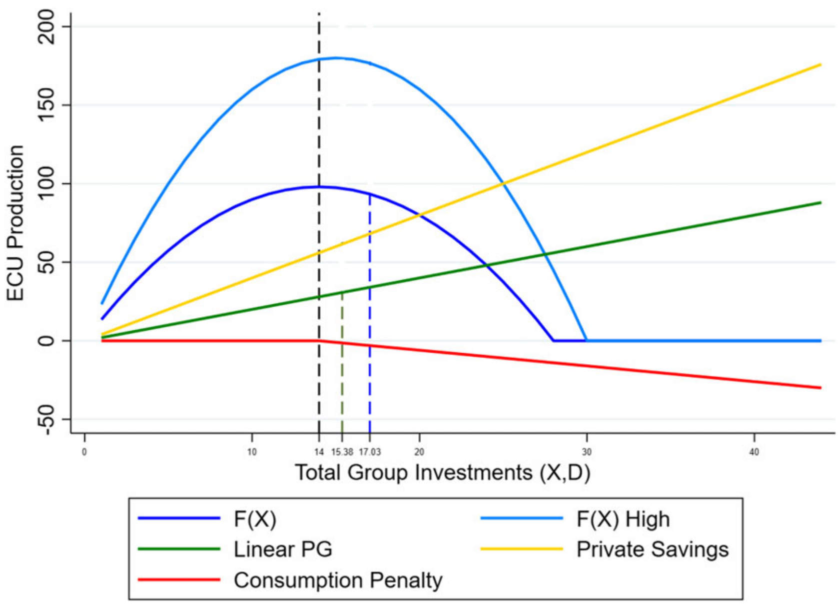

Figure 8. Group production functions with spillovers and group mean investments.

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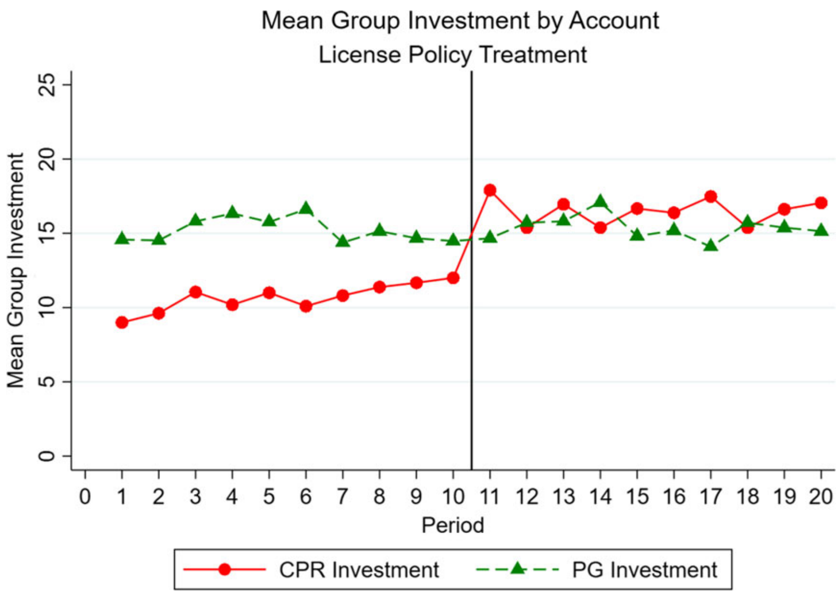

Figure 9. License policy means.

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 exceeded the spillover, because of the negative spillover from the CPR, groups could not 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 in line with the experimental public goods literature, there is a significant nontrivial investment in the PG account that is not suggestive of free riding. After the tenth round, when the license policy was revoked, there was little to no change in the group level of PG investment, but there was a significant jump in CPR investment, with all group members allowed to invest.

Table 7 provides OLS estimates of the treatment effect of removing the licensing policy, including the same controls used in the spillover treatment analysis.[10] Similar to the estimates for the spillover treatment, I find no correlation between the information structure of revealing group investments between rounds and the subject response to the policy treatment. Removing the licensing policy led to an increase of 4.787 tokens invested per subject in the CPR, with no discernible effect on the PG account. The effect of having a license for the first ten 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 not holding a license for the first ten rounds. However, the policy treatment for those with licenses for the first ten rounds is not 3.3 tokens, as described earlier. Those with a license

[10]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 to the spillover treatment sessions, hence the Pay Scale indicator used in my analysis

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Table 7. License policy treatment effect on account spending (FE OLS)

	CPR investment			PG donations		
	(1)	(2)	(3)	(4)	(5)	(6)
License Policy Treatment Effect	2.012*** (0.273)	2.127*** (0.385)	4.787*** (0.676)	0.143 (0.278)	0.272 (0.354)	−0.331 (0.957)
License Holder Indicator	2.862*** (0.304)	2.861*** (0.305)	5.341*** (0.191)	−0.298 (0.338)	−0.305 (0.337)	−1.102** (0.451)
License Holder × Treatment	–	–	−4.959*** (0.560	–	–	1.594*** (0.510)
Time Lag	–	0.001 (0.002)	0.002 (0.002)	–	0.002 (0.002)	−0.002 (0.002)
Time Lag × Treatment	–	–	−0.003 (0.004)	–	–	0.007** (0.002)
CPR Lag	–	0.075*** (0.020)	0.096*** (0.023)	–	0.032** (0.011)	0.052* (0.028)
PG Lag	–	0.029** (0.011)	0.020** (0.044)	–	0.132*** (0.026)	0.135*** (0.026)
CPR Lag × Treatment	–	–	−0.036 (0.037)	–	–	−0.023 (0.041)
PG Lag × Treatment	–	–	0.014 (0.015)	–	–	−0.008 (0.018)
Pay Scale Change	0.779*** (0.253)	0.584*** (0.125)	0.351** (0.167)	−0.079 (0.505)	−0.106 (0.224)	0.055 (0.211)
Pay Scale × Treatment	–	–	0.567** (0.244)	–	–	−0.483 (0.315)
Constant	0.332 (0.248)	−1.376*** (0.415)	−2.795*** (0.430)	3.751*** (0.514)	1.068 (0.742)	1.512 (0.906)
Period Fixed Effects	Y	Y	Y	Y	Y	Y
Session Fixed Effects	Y	Y	Y	Y	Y	Y
Obs	1680					
R^2	0.323	0.331	0.517	0.026	0.097	0.114

Reported standard errors are clustered at the group level.

Table 8. Sign rank and sum rank tests of licensing effects on CPR investment

	Sign	Obs	Sum ranks	Expected	*Z* score
License Policy Effect					
(Sign Rank)	Positive	32	958	1784.5	−3.686***
	Negative	51	2611	1784.5	
	Zero	1	1	1	
Licensure Effects					
(Rank Sum Tests)		Obs	Rank Sum	Expected	Z Score
Period 1–10	Licensed	42	2667	1785	−8.436***
	Not Licensed	42	903	1785	
Period 11–20	Licensed	42	1890.5	1785	−0.944
	Not Licensed	42	1679.5	1785	

Table 9. Sign rank and sum rank tests of licensing effects on public good donations

	Sign	Obs	Sum Ranks	Expected	Z Score
License Policy Effect					
(Sign Rank)	Positive	40	1747	1777.5	−0.136
	Negative	39	1808	1777.5	
	Zero	5	15	15	
Licensure Effects					
(Rank Sum Tests)		Obs	Rank Sum	Expected	Z Score
Period 1–10	Licensed	42	1494	1785	2.604***
	Not Licensed	42	2076	1785	
Period 11–20	Licensed	42	1910	1785	−1.119
	Not Licensed	42	1660	1785	

consistently invested approximately one token less in the final ten rounds than in the first 10.

Non-parametric pairwise estimates of the license policy effect can be found in Tables 8 and 9, illustrating the policy effect on the CPR and PG, respectively. As in the case of the spillover treatment sequence, I use sign-rank tests to evaluate the within-subjects treatment effect and rank-sum tests to evaluate the effect of having a license in the first ten games on individual investment and donation decisions. Removing the licensing policy led to a significant decrease in individual CPR investments but no observable effect on public good donations. In addition, there is a significant difference between the volume of PG donations for licensed and unlicensed subjects for the first ten games. Unlicensed subjects consistently contributed donations to the public good despite not directly benefiting from

Table 10. Sign rank and sum rank tests of licensing effects on profit (USD))

	Sign	Obs	Sum ranks	Expected	*Z* score
License Policy Effect					
(Sign Rank)	Positive	50	2328	1785	2.422**
	Negative	34	1242	1785	
	Zero	0	0	0	
Licensure Effects					
(Rank Sum Tests)		Obs	Rank Sum	Expected	Z Score
Period 1–10	Licensed	42	2476	1785	−6.182***
	Not Licensed	42	1094	1785	
Period 11–20	Licensed	42	1780.5	1785	0.040
	Not Licensed	42	1789.5	1785	

Table 11. Sign rank test of licensing policy treatment on profit by licensed status (USD)

	Sign	Obs	Sum ranks	Expected	*Z* score
Licensed subjects	Positive	40	888	451.5	5.458***
	Negative	2	15	451.5	
	Zero	0	0	0	
Unlicensed Subjects	Positive	10	113	451.5	−4.232***
	Negative	32	790	451.5	
	Zero	0	0	0	

the PG spillover. There are no observable differences between subjects who initially had licenses and those who did not in the final ten games.

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 10 and 11 provide tests of the licensing policy treatment effect across groups and between those who 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 who 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.

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 increased 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 ten games played on average. For comparison, with the license policy in effect, the CPR threshold could not be crossed, and groups only failed to meet the PG threshold in

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approximately 1 out of the ten games played. Despite no change in group earnings following the policy removal, there is a corresponding increase in the likelihood that groups inefficiently cross the CPR threshold and reduce the public good's value.

Conclusion and discussion

Despite the many scenarios in the natural resource field for which we can model resource use as a multidimensional problem of investing in production and donating towards conservation, there has been little exploration into how spillovers between these two resource demands affect resource use. This paper contributes to the natural resource and experimental literature by allowing a resource pool to have value in depletion and conservation. Moreover, the model and experiment allow policy and externalities based on nature to be explored in this economic setting.

My model introduces a combined resource pool game with a common pool investment (consumption) aspect and a public good donation (conservation) aspect that extends resource management problems 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 impact preferences toward 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, resource account spillovers significantly improve the provision of a public good meant to represent conservation efforts 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 treatment effect helps illustrate how the appropriators of a resource most often realize the benefits of conservation. Moreover, the positive result observed for public good provision illustrates how those providing towards conservation efforts are often the resource appropriators themselves.

Evaluating an investment-capped license lottery policy motivated by an active US hunting and fishing policy, I find a significant increase in common pool investment upon removing such a policy, supporting Hypothesis 3. Those who were once precluded from investing in the CPR are the major contributors to this effect, as those who had previously been allocated licenses marginally decreased their investment when their full group could utilize the CPR account. While there were periodic instances of the resource pool collapsing from this heightened investment, there is no evidence to suggest a decrease in the average group's welfare.

Because subjects within an experimental session knew the timing of treatment effects, there is a high likelihood that tests comparing the choices of a single group across treatment conditions underestimate the effects of spillovers and the modeled licensing policy on investment decisions. In anticipation of the treatment effects, subjects may use their group's investment decisions from previous games played as a signal to inform their future choices. While the payoffs may be independent between games played, we cannot assume the actions of a group are independent between rounds due to the fixed groups and public information provided on a group's decisions. This is a methodological error on the author's part; however, this bias only impacts the within-subjects sign-rank tests and OLS specifications that compare outcomes within a group across treatment blocks. The sum-rank tests used to evaluate across groups of subjects from different sessions are unaffected as they measure the treatment effect on group choices across separate sessions.

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Beyond accounting for methodological errors, future extensions of this work can incorporate a broader array of choices that can better replicate the preferences of resource stakeholders within the experimental environment. As mentioned in Footnote 5, the constructed model assumes that the hunting activity represented only considers activities that may be commercially viable. This fails to recognize or incorporate the market for recreational hunting and harvests. In the case of wolf or deer hunts, there may be no commercial incentive on the hunter's part; instead, the activity itself provides utility.

Extensions to the licensing policy treatment that allows for noncommercial incentives may involve allowing license holders to engage in an alternative activity to the investment task. For example, they may spend their quota playing a rudimentary game (word search, minesweeper, etc.) without earning additional financial benefits.

Additionally, this study's model and accompanying experiment focus on the static efficiency of a hunting activity. However, due to the dynamic fluctuations of wildlife stock after a hunting season, it may be more prudent to observe this environment from the perspective of dynamic efficiency. To compensate for this, the game model may be amended for the future into a dynamic game where the payoff function for the CPR may contract following periods where the common pool was over-invested in and rebound in later periods if there is an efficient decrease in common pool investment.

Further extensions to future work may also 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 experiments 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 increasing stakeholder group size in the absence of a licensing policy.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/age.2025.3

Data availability statement. The data that supports the findings of this study, as well as all code used in sampling and analysis, can be found in the following repository: https://github.com/ExpEc65537/CPR-Experiment

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