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Abstract: We develop a theoretical model of endogenous CPR coalition formation in which the resource is co-defended with costly monitoring by coalition members and sanctions for encroachment imposed by the government. We demonstrate that CPR coalitions can form even when monitoring is so costly that coalition members choose not to monitor for encroachment, but the coalitions will be relatively small. Larger coalitions will form if monitoring costs are low enough to yield effective deterrence. We tested the results of the model using lab-in-field experiments with fishers who were members of Chile's territorial use rights fisheries (TURFs) and in the lab with Chilean university students. We find that fishers frequently formed CPR coalitions, even when they could not deter outsider poaching. Fishers usually formed the grand coalition when the monitoring cost was low, but they formed smaller coalitions when monitoring was more costly. Fishers invested in monitoring frequently and these investments reduced poaching. Relative to open access, when coalitions formed, total harvest effort was curtailed and earnings for coalition members generally increased. Students formed coalitions less frequently, these coalitions tended to be small, and they infrequently invested in monitoring, even when it was profitable to do so. Consequently, student coalition member earnings were not better off on average than under open access.

JEL Codes: C93, K42, Q20, D71, H40

Keywords: Common pool resources; experimental economics; field experiments; coalition formation; enforcement; social dilemma; poaching; encroachment

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The Endogenous Formation of Common Pool Resource Coalitions

1. Introduction

Successfully managed common pool resources (CPR) have clearly defined boundaries that are effectively defended from outsider encroachment (Ostrom, 1990; Ostrom, 2009; Ostrom, 2010; Morrow & Hull, 1996). Typically, defending CPR boundaries involves a hybrid co-enforcement strategy between CPR users and government authorities. While CPR coalition members often monitor the boundaries of their resource, their options for imposing sanctions are limited. It is often left to a government authority to prosecute encroachers and impose sanctions (Chávez, et al., 2018; Gelcich, et al., 2009; Gelcich, et al., 2017; Quynh, et al., 2017; Quynh, et al., 2018).[1]

Several authors have examined the dual problem of managing a CPR and defending it against encroachment (Chávez, et al., 2018; Chhatre & Agrawal, 2008; De Geest, et al., 2017; Kaffine, 2009; Robinson, et al., 2014). These studies typically assume the existence of a CPR user group that must coordinate internal use and defensive actions. However, we hypothesize that the ability to deter outsiders affects the formation of common property institutions in the first place. Hence, we study a situation in which resource users may form a coalition to gain exclusive legal rights to a resource. Encroachment by outsiders is possible, so both the coalition and the government co-enforce access to the resource. Our study focuses on how the difficulty of deterring encroachment affects the formation of CPR coalitions, the size of these coalitions, levels of encroachment, conservation of resources, and economic efficiency. We develop a theoretical model of CPR coalition formation and deterrence and then test the model using framed field experiments with Chilean near-shore fishers whose livelihood depends upon successful management of a CPR and deterrence of poaching from the resource. This approach recognizes that life experience, cultural and environmental conditions, and context of the experiment may influence the experimental behavior of participants (Cárdenas & Ostrom, 2004; Henrich, et al., 2010). In light of the recent emphasis on replication in the social sciences (Camerer, et al., 2016;

[1] There are also examples of extra-legal and illegal attempts to impose sanctions to protect CPR boundaries by, for example confiscating or destroying an encroacher's equipment (Acheson, 1988) or using aggressive behavior and sometimes violence (Kaffine, 2009; Mixon, 2014; Muchapondwa, et al., 2014; Aguila, 2016).

Dreber, et al., 2015; Bohanon, 2015), we also replicated the experiment in the lab with Chilean university students

Although our work is motivated by the general problem of excluding outsiders from encroaching upon a CPR, our experiments were framed as a decision to join a coalition to manage a benthic mollusk called *loco* or Chilean abalone. The experiment participants were members of fishing organizations in Chile's area-based fishing rights program, commonly referred to as a territorial use rights for fishing program (TURF). These programs grant a specific group of fishers exclusive rights to harvest from a specific area. The idea is that by limiting access to the resource, fishing organizations can coordinate their harvests to maximize group benefits and prevent the over-exploitation that occurs in an open-access regime (Ostrom, et al., 1992). In Chile's TURF program, fishers must form a fishing organization and apply to the government for exclusive access to a particular fishing area. Thus, fishing organizations are formed endogenously.[2]

While our experiments were framed in terms of Chile's TURF program, the insights we gain in this study are applicable to a wide range of CPR situations, including other cooperative arrangements to manage fisheries (Deacon, 2012; Ovando, et al., 2013), the use and protection of community forests, and the establishment and enforcement of collective land rights. Community forest management programs give local communities rights to harvest and manage local forests. The allocation of these rights to organizations of local villagers and involving them in monitoring and enforcing access can reduce forest degradation (Chhatre & Agrawal, 2008; Robinson, et al., 2014). On the other hand, the inability to deter outsiders can lead to the failure of these programs (Morrow & Hull, 1996). Similarly, secure collective land titles help safeguard the rights of local communities to manage their territories and protect them from expropriation and encroachment by outsiders (BenYishay, et al., 2017; Blackman, et al., 2017; Peña, et al., 2017). Like other area-based common property institutions, the value of collective land titles often depends on efforts by local communities and the government to deter encroachment by outsiders (Lobo & Vélez, 2020; Vélez, 2011).

In our theoretical model of CPR coalition formation, the boundaries of the resource are co-defended by costly monitoring by the CPR coalition members and exogenous sanctions for

[2] For a recent review of many TURF schemes around the world see Quynh, et al., (2017). See Chávez, et al., (2018) for a discussion of the Chilean TURF program. An analysis of case studies of TURF organizations in Japan and Chile is presented in Cancino, et al., (2007).

encroachment imposed by a government authority. We demonstrate that CPR coalitions can form even when monitoring is so costly that coalition members choose not to monitor for encroachment, but the coalitions will be relatively small and some individuals will choose not to join the coalition. On the other hand, larger coalitions will form if monitoring costs are low enough to yield effective deterrence. The formation of a CPR coalition always leads to lower exploitation of the resource and higher earnings for coalition members relative to the open-access situation; these effects are strongest when the cost of monitoring is low and larger coalitions form.

The main results of our field experiments with fishers are as follows. We find that the fishers formed CPR coalitions frequently, even when they could not deter outsider poaching or monitoring was unprofitably expensive. Fishers usually formed the grand coalition when the monitoring cost was low; they formed smaller coalitions when deterrence was more costly or not available. Fishers also invested in monitoring frequently, in fact, more frequently than predicted. These investments reduced, but did not eliminate, poaching. Coalition formation, with and without investments in monitoring, led to reduced pressure on the resource. Finally, the fishers were significantly better off joining a CPR coalition when the monitoring cost was low relative to the open access situation and relative to when the cost of monitoring was high. As expected, coalition members were not significantly better off than under open access when they could not invest in monitoring and when the cost of monitoring was high.

The results from the university student sample are quite different. Students formed coalitions less frequently and these coalitions tended to be small. Moreover, student coalition members did not invest in monitoring very often, even when it was profitable to do so. As with the fishers, coalition formation reduced total harvest effort and investing in monitoring reduced encroachment. However, student coalition members were not better off than under open access and they were strictly worse off in some treatments.

Our results have several important implications for the design and maintenance of area-based property rights policies. First, our results suggest that CPR coalitions can form endogenously under the right institutional, legal, and social conditions. These conditions include enabling organized CPR users to claim sole responsibility for a resource and to work with government authorities to prevent encroachment by outsiders. Second, the ability to deter encroachment at reasonable cost affects the size of CPR coalitions, their profitability and, potentially, their sustainability. CPR coalitions can still form when co-enforcement is not sufficient to deter outsiders, but these groups will likely be small and not significantly more profitable than under open access. It seems likely that such small coalitions will not be as resilient as larger, more profitable groups. In contrast, our results also suggest that endogenous CPR coalitions can be larger, more profitable, and likely more resilient when encroachers can be deterred efficiently. Finally, our results suggest that, in addition to enabling the formation of CPR coalitions, government authorities can help make CPR coalitions more inclusive and profitable by contributing to the defense of CPR boundaries. These contributions may include establishing significant encroachment sanctions and establishing effective protocols for prosecuting and penalizing encroachers. Government authorities may also make their own contributions to monitoring, especially contributions that would complement CPR coalition efforts.

The remainder of this paper proceeds as follows. In the next section, we review the related literature. In section 3, we develop a theoretical model of endogenous formation of CPR coalitions, incorporating encroachment and deterrence. This model motivates the design of our experiments, which we present in section 4. In section 5, we present our results and we conclude in section 6.

2. Related literature

Our work contributes to a literature on deterring encroachment on CPRs using laboratory and laboratory-in-field experiments. Schmitt, et al. (2000) documented how undeterred poaching almost completely eliminates CPR users' willingness to cooperate with each other. With lab experiments in which members of a CPR coalition could sanction both insiders and outsiders, De Geest, et al. (2017) found that CPR members were willing to punish outsider encroachment, but they were not willing to impose high enough sanctions to fully deter outsiders. Like our study, Chávez, et al. (2018) used lab-in-field experiments with members of the Chilean TURF program and university students to examine the problem of co-enforcing CPR boundaries, with and without government assistance in monitoring. The authors found that subjects had difficulty coordinating efforts to deter encroachment, even with contributions to monitoring from the government.[3] The experimental literature on deterring encroachment complements work from theoretical (Robinson,

[3] The literature on defending the boundaries of a CPR using experiments is distinct from the related literature on enforcement by an external authority of individual restrictions within fixed groups of CPR users (Abatayo & Lynham, 2016; Cardenas, et al., 2000; Leibbrandt & Lynham, 2018; Lopez, et al., 2012; Vélez, et al., 2010), and the literature on mutual monitoring and sanctioning within CPR groups to limit over-use by other group members (Casari & Plott, 2003; Cason & Gangadharan, 2015; Ostrom, et al., 1992; Vollan, et al., 2019).

et al., 2014), empirical (Chhatre & Agrawal, 2008), and case-study approaches (Vélez, 2011), which also highlight the importance of co-enforcement efforts to help deter encroachment for the success of CPR management.

Each of the small number of existing experimental studies on deterring encroachment on CPRs assumes fixed groups of CPR users and potential encroachers. Our study makes an important contribution to this specific literature, and to the much larger literature that uses economic experiments to study CPR management, by making the formation of CPR coalitions endogenous. We find that the ease or difficulty of deterring outsiders has an important impact on the size and profitability of CPR coalitions.

Because our study features the endogenous formation of CPR coalitions, our work is also a novel contribution to the literature on endogenous group formation. One popular approach examines stable cooperative coalitions, which has been used extensively to study the formation of coalitions to provide public goods, in particular the formation of international agreements to confront transboundary environmental problems. This literature includes both theoretical contributions (Barrett, 1994; Barrett, 2003; Carraro & Siniscalco, 1993; Finus & Pintassilgo, 2013; Finus & McGinty, 2019) and results from lab experiments (Kosfeld, et al., 2009; McEvoy, et al., 2010; Dannenberg, et al., 2014). Typically, coalition formation to provide public goods suffers from the "paradox of cooperation" (Finus & McGinty, 2019); that is, coalitions to provide public goods tend to be small and not very effective at improving the welfare of coalition members. Some authors have studied the formation of coalitions to confront the depletion of international open access fisheries from a theoretical perspective (Kronbak & Lindroos, 2007; Kwon, 2006; Miller & Nkuiya, 2016; Pintassilgo, 2003; Pintassilgo, et al., 2010). They too find that stable international fishing coalitions are likely to be small and not very effective. Larger stable coalitions are possible with auxiliary features like minimum participation requirements (McEvoy, et al., 2015), scientific uncertainty about the possibility of environmental catastrophe (Barrett & Dannenberg, 2012), and trade sanctions against non-participants (Barrett, 2003; Nordhaus, 2015).[4] To our knowledge, the

[4] A related literature on endogenous coalition formation focuses on the effects on cooperation of endogenous and exogenous sorting of conditional cooperators and free-riders into coalitions. This literature reveals that the composition of coalitions plays an important role in sustaining cooperation in social dilemma experiments. See Guido, et al. (2019) for a thorough literature review. Our study differs from papers in this literature, because they typically do not employ the concept of coalitional stability that is so important in our study, and because we do not attempt to identify player types to examine coalition-composition effects on the formation of CPR coalitions.

coalitional-stability approach has not been used to study the formation of CPR coalitions that invest to help defend their resource from outside encroachment. We demonstrate, both theoretically and with experiments, that the ease or difficulty of deterring encroachment plays an important role in determining the size of CPR coalitions. If outsiders can be excluded efficiently, then larger more productive CPR coalitions can form. The reason is that effective deterrence excludes outsiders from exploiting the resource, which reduces the value of being an outsider and makes joining a CPR group more attractive. This finding is similar to the findings of Barrett (2003) and Nordhaus (2015) who show theoretically that trade sanctions against freeriding non-participants can lead to large stable international environmental agreements. Trade sanctions, like exclusion from a CPR, can reduce the value of freeriding and make participation in an international environmental agreement more attractive.

3. Theoretical model

In this section we present the theoretical model that guides the design of our experiments. The model is a static, linear common pool resource game, with the possibility that a coalition may form to restrict their own use of the resource and deter encroachment by those outside the coalition.

3.1 Model fundamentals

Coalition formation can produce insiders and outsiders. In our game there are a fixed number of n players, and we denote the number of players inside a coalition as n_i and the number of outsiders as n_o (n_i and n_o are always integers). Each player has a time endowment, $x = 1$. The time spent harvesting a common pool resource by individual j in group z is $e_{zj} \in (0, ½, 1)$; that is, an individual spends all, one-half, or none of their time harvesting the resource. Let a denote the individual marginal benefit from time spent harvesting, net of harvesting costs. Let d be the marginal congestion cost from harvesting as in a typical static renewable resource model. Individuals can also devote time to a pursuit that is unrelated to the resource with marginal benefit w.

The individuals are in an open-access situation in the absence of a CPR coalition. Since we do not need the insider/outsider designation in this situation, let e_j denote individual harvesting time. Then, the payoff function for individual j is

$$b_j = T + ae_j + w(x - e_j) - dE, \tag{1}$$

where $E = \sum_{k=1}^{n} e_k$ and T is a fixed non-negative value. We assume throughout that $a - w - d > 0$ so that each individual spends all of their time endowment harvesting in the open-access equilibrium. Substituting $e_j = 1$ for every harvester into (1) gives us symmetric payoff for each individual in the open access equilibrium, $b_{oa} = T + a - dn$. In our experiments we choose parameters so that

$$a - w - dn = 0. \tag{2}$$

With this assumption,

$$b_{oa} = T + w, \tag{3}$$

which implies that every individual is indifferent between not harvesting and harvesting in the open access situation. However, harvesting at capacity is more lucrative than an individual's outside option if others do not harvest, or if some others form a coalition to limit their harvests.

Membership in a CPR coalition. To confront the inefficiency of open access exploitation of the resource, individuals may form a coalition to limit their harvests. Individuals who join a CPR coalition are required to limit their time spent harvesting to one-half unit. The other half-unit can be devoted to the outside option. Joining a CPR coalition can give members additional benefits, including benefits from better access to markets and the benefits of joint transportation and marketing efforts. Let s be an individual's extra payoff from joining a coalition.

To preserve the motivation to freeride on the conservation efforts of a CPR coalition, assume that a coalition member would rather leave the coalition and increase their time harvesting the resource as long as the coalition stays intact and there are no other consequences of defection. If an individual leaves a coalition and uses all of their time harvesting the resource, they gain $(a - d)/2$. However, they lose the value of the time spent in the outside option $w/2$ plus the extra benefit s of being a member of the coalition. Therefore, we assume the following holds throughout:

$$\frac{a - d}{2} > \frac{w}{2} + s. \tag{4}$$

Monitoring. Coalition insiders may also decide collectively to invest in a monitoring technology to help deter the outsiders from poaching the resource. If the insiders decide to invest in the monitoring technology, they each bear an equal share of its cost. If detected, poachers face a fixed per unit fine for time poaching f that is exogenous as if imposed by a government authority.

Note well the co-enforcement aspect of the game: the CPR coalition may invest in monitoring, while sanctions for detected poaching are the responsibility of an outside authority. The probability an outsider is monitored is p, and let c be the marginal cost to a coalition of establishing p. The marginal cost of monitoring is our primary treatment variable. The total cost to the coalition of establishing p is cp and an insider's share of this cost is $cp\ /n_i$.[5] If the grand coalition forms, there are no outsiders to monitor. Likewise, if no coalition forms there is no one to invest in monitoring. Therefore, $p = 0$ for $n_i = n$ and for $n_i = 0$.

Payoffs. Since each insider is required to limit their time harvesting to $e_{ij} = 1/2$, we can write the payoff function for an insider in a coalition of size n_i as

$$b_i(n_i) = \begin{cases} T + s + \frac{1}{2}(a + w - dn_i) - dE_o - cp\ /n_i\,, & \text{for } 0 < n_i < n; \\ T + s + \frac{1}{2}(a + w - dn), & \text{for } n_i = n. \end{cases} \tag{5}$$

In (5), E_o is the total amount of time spend poaching the resource by the outsiders. We do not include the j subscript to distinguish a particular insider's payoff function, because they are equal by design and we will focus exclusively on symmetric outcomes.

Given $e_{ij} = 1/2$ for all insiders, the payoff function for an outsider is

$$b_{oj}(e_{oj}, n_i) = \begin{cases} T + ae_{oj} + w(x - e_{oj}) - d\left(\frac{n_i}{2} + E_o\right) - pfe_{oj}, & \text{for } e_{oj} > 0 \text{ and } n_i \geq 1; \\ T + ae_{oj} + w(x - e_{oj}) - dE_o, & \text{for } e_{oj} > 0 \text{ and } n_i = 0; \\ T + w, & \text{for } e_{oj} = 0. \end{cases} \tag{6}$$

The payoff for an outsider choosing $e_{oj} > 0$ is straightforward. However, if an outsider chooses not to harvest so that $e_{oj} = 0$, they are not affected by the external costs of others' harvests and they do not incur the risk of being fined. Therefore, the payoff of an outsider's who does not harvest the resource is $b_{oj} = T + w$.

The grand coalition versus open access. If the grand coalition forms a CPR cooperative, then each individual earns

$$b_i(n) = T + s + \frac{1}{2}(a + w - dn).$$

[5] Notice that the cost of monitoring does not depend on the number of outsiders. This can be justified by assuming that monitoring is of the geographical area of the resource, not individual outsiders.

Recall from (3) that the individual payoff in the open access outcome is $b_{oa} = T + w$. Use the assumption that $a - w - dn = 0$ from (2) and subtract the two payoffs to obtain

$$b_i(n) - b_{oa} = s.$$

That $b_i(n) - b_{oa} > 0$ demonstrates that a CPR coalition of all the harvesters is more valuable than the open access situation.

3.2 Coalition formation game

The coalition formation game is a sequential game. The stages of the game are in Figure 1. In the first stage, individuals decide independently (i.e., without communication) and sequentially whether to join a coalition. If a CPR coalition does not form, then all subjects decide how much time they will spend harvesting the resource. They make these decisions simultaneously and independently. In our experiments, we require that at least two individuals join a CPR coalition for one to form. We do this because of the common understanding of a coalition or a group as containing multiple individuals. We adopt this requirement as we continue to develop our model. If a coalition forms, the coalition members first decide collectively whether to invest in the monitoring technology. All individuals know the group monitoring decision. Given that a coalition forms, harvesting the resource follows after the coalition makes its monitoring decision. The coalition members devote their half-unit of time to harvesting as required by the coalition rules, while the outsiders decide how much of their time allocation to devote to harvesting (i.e., poaching) the resource. If the insiders do not invest in monitoring, the game ends after the harvesting stage. If the insiders invest in monitoring, the game proceeds to an enforcement stage in which outsiders are monitored with the probability determined by the monitoring technology, and the exogenous sanction is imposed on any outsider that is caught poaching. We examine potential subgame perfect equilibria of this game via backward induction.

A coalition forms and the insiders invest in monitoring. If a coalition forms and invests in monitoring it must have between two and $n - 1$ members, because there are no outsiders if the grand coalition forms. Consider an outsider's choice to harvest the resource. Outsiders can choose to spend all or half of their time harvesting the resource. Using (6) we can calculate

$$b_{oj}(e_{oj} = 1, n_i) - b_{oj}(e_{oj} = 1/2, n_i) = \frac{a - w - d - pf}{2},$$

which reveals that, conditional on harvesting the resource, an individual's choice of time spent harvesting is determined by

$$e_{oj} = \begin{cases} 1 \text{ if } a - w - d > pf \\ 1/2 \text{ if } a - w - d < pf. \end{cases} \tag{7}$$

We ignore the possibility that $a - w - d = pf$.

Now consider whether an outsider will spend any time harvesting. Condition (7) applies to each outsider so each of them makes the same harvesting choice. In the case that they all choose $e_o = 1$, their payoffs are

$$b_o(e_o = 1, n_i) = T + a - d\left(n - \frac{n_i}{2}\right) - pf.$$

We have dropped the subscript j distinguishing particular outsiders because of our focus on symmetric outcomes. If all the outsiders choose $e_o = 1/2$, their payoffs are

$$b_o(e_o = 1/2, n_i) = T + w - \frac{pf}{2}.$$

Recall from (6) that an outsider who does not spend any time harvesting the resource has payoff $b_o(e_o = 0) = T + w$. Calculate:

$$b_o(e_o = 1, n_i) - b_o(e_o = 0, n_i) = \frac{dn_i}{2} - pf;$$

$$b_o(e_o = 1/2, n_i) - b_o(e_o = 0, n_i) = -\frac{pf}{2}.$$

Since $b_o(e_o = 1/2, n_i) - b_o(e_o = 0, n_i) < 0$, if outsiders would only choose to spend half their time poaching, they would not poach at all. Thus, using (7), if $a - w - d < pf$, then outsiders are deterred from poaching. However, if $a - w - d > pf$ so that outsiders would spend all of their time poaching, they are deterred from encroachment if $b_o(e_o = 1, n_i) < b_o(e_o = 0, n_i)$, which occurs if $dn_i/2 < pf$. In sum, outsiders are deterred if

$$pf > \min\left\{a - w - d, \frac{dn_i}{2}\right\}. \tag{8}$$

If (8) does not hold, outsiders will spend all of their time encroaching on the resource.

Whether the outsiders are deterred or not, by assumption each insider will devote one-half unit of time to harvesting and the other half of their time to their alternative pursuit.

A coalition forms and the insiders do not invest in monitoring. If a coalition forms and it does not invest in monitoring, then $p = 0$ and (8) does not hold. In this case, each outsider will use all of their time harvesting the resource and each insider will limit their harvests to half of their time endowment.

A coalition forms and the insiders choose whether to invest in monitoring. Now consider whether coalition insiders will invest in monitoring. This question is only relevant for coalitions $n_i \in (1, n)$. The insiders can invest in a technology that allows monitoring of outsiders with probability p that satisfies (8). This implies that the insiders can deter the outsiders if they decide to invest enough to pay for the monitoring technology. If the insiders cannot agree to invest enough to implement the monitoring technology, they bear no monitoring costs, the outsiders are not monitored and they are not deterred from poaching.

If the insiders invest in monitoring, using (5) each of their payoffs is

$$b_i^d(n_i) = T + s + \frac{1}{2}(a + w - dn_i) - \frac{cp}{n_i}. \tag{9}$$

The superscript d indicates that the outsiders are deterred from poaching. Each of the outsiders earns their payoff away from the resource,

$$b_o^d(n_i) = T + w. \tag{10}$$

If the insiders cannot invest enough to implement monitoring, then they invest nothing and the outsiders enter and poach to capacity. Each insiders' payoff is then

$$b_i^{nd}(n_i) = T + s + \frac{1}{2}(a + w + dn_i) - dn, \tag{11}$$

and each outsider's payoff is

$$b_0^{nd}(n_i) = T + a - d\left(n - \frac{n_i}{2}\right), \tag{12}$$

(The superscript nd indicates that the outsiders are not deterred.) Calculate

$$b_i^d(n_i) - b_i^{nd}(n_i) = -\frac{cp}{n_i} + dn_o. \tag{2}$$

With (13) we conclude that a coalition with $n_i \in (1, n)$ members will collectively choose to monitor and deter the outsiders from encroachment if and only if the marginal cost of monitoring does not exceed

$$\bar{c}(p, n_i) = \frac{dn_o n_i}{p} = \frac{d(n - n_i)n_i}{p}. \tag{3}$$

Note that $\bar{c}(p, n_i)$ is decreasing in p. The intuition is that since establishing a higher monitoring probability is costly, the maximum marginal cost for which deterrence is worthwhile is lower. In addition, for $n_i \in (1, n)$: $\bar{c}(p, n_i)$ is strictly positive; it is strictly concave in n_i; it reaches a maximum at $\bar{c}(p, n_i) = dn^2/4p$ where $n_i = n/2$; and $\bar{c}(p, n_i) = d(n-1)/p$ for $n_i = 1$ and $n_i = n$. Thus, coalitions will always invest in monitoring to deter outsiders if $c < d(n-1)/p$, but no coalition would invest in monitoring if $c > dn^2/4p$. For c strictly between $d(n-1)/p$ and $dn^2/4p$, small coalitions and large coalitions will not invest in monitoring, while coalitions of intermediate size will. Small coalitions will not monitor because there are not enough coalition members to share the monitoring costs profitably. Large coalitions will not monitor, because the externality that a small number of poachers impose on the insiders is too small to justify the monitoring cost.

We have completed the description of possible subgame equilibria, given the formation of a coalition $n_i \in (1, n)$. Table 1 summarizes these potential equilibria.

3.3 Stable coalitions

At the beginning of the game each individual decides independently whether to join a CPR coalition. In our experiments, these membership choices were made sequentially under perfect information. Following the literature on coalitional stability (e.g., Barrett, 1994; Finus & McGinty, 2019), an equilibrium coalition size is one that is internally and externally stable in the sense that no member wishes to leave and no non-member wishes to join. That is, for identical players, an equilibrium coalition satisfies:

$$b_i(n_i) \geq b_o(n_i - 1); \quad (internal\ stability) \tag{4}$$

$$b_o(n_i) \geq b_i(n_i + 1). \quad (external\ stability) \tag{5}$$

Since the payoffs to insiders and outsiders depend on whether the insiders find it advantageous to deter the outsiders, the equilibrium coalition size depends on whether the insiders make the required investment in monitoring. Our first proposition identifies the equilibrium coalition size when the insiders do not invest in monitoring the outsiders. The proof of the proposition is in the appendix.

Proposition 1: If the members of a coalition do not find it advantageous to deter the outsiders, then the unique equilibrium coalition size is the smallest profitable coalition. Explicitly, the equilibrium coalition size is

$$n_i^{nd} = \min\{n_i | n_i \geq n_i^0\}, \tag{6}$$

where

$$n_i^0 = \frac{a - w - 2s}{d}. \tag{7}$$

Moreover, $n_i^{nd} \in (1, n)$.

Proposition 1 is similar to common findings in the related literature on international environmental agreements and agreements to limit depletion of open-access fisheries (Barrett, 1994; Kronbak & Lindroos, 2007; Kwon, 2006; Miller & Nkuiya, 2016; Pintassilgo, et al., 2010).[6] This literature suggests that stable coalitions are typically small and not very profitable for coalition members unless there are other features that make freeriding less attractive (e.g., trade sanctions). Proposition 1 suggests that CPR coalitions can form even when encroachment cannot be deterred, but these coalitions will tend to be small and not very profitable relative to open access.

However, CPR coalitions can be larger, up to and including the grand coalition, when outsiders can be deterred. The following proposition reveals that the grand coalition can be the uniquely stable coalition size if the cost of deterring outsiders is low enough. Its proof is in the appendix.

Proposition 2: The grand coalition is the unique stable coalition if

$$c < \min\left\{\frac{d(n-1)}{p}, \frac{(n_i+1)\big(2s + a - w - d(n_i+1)\big)}{2p}\right\}. \tag{19}$$

Each of the elements in (19) is strictly positive. Therefore, there always exist strictly positive values of c for which the grand coalition is the unique stable coalition.

3.4 Simulations

To illustrate how the equilibrium CPR coalition size varies, we simulate insiders' and outsiders' symmetric individual payoffs and graph them in Figure 2. Each panel is constructed with parameters $n = 6$, $T = 400$, $a = 1{,}760$, $w = 320$, $d = 240$, $s = 400$, $f = 1{,}280$, and $p =$

[6] The equilibrium CPR coalition size n_i^{nd} is usually derived under the assumption of simultaneous membership choices, but this is also the outcome of sequential membership choices under perfect information that we feature in our experiments. Specifically, the subgame perfect outcome of the coalition formation game is that the first $n - n_i^{nd}$ players to make their choices opt out of the coalition while the remaining n_i^{nd} individuals join. See McEvoy, et al. (2015). Moreover, $n_i = 0$ is always a stable coalition size, but this outcome cannot be part of a subgame perfect equilibrium when membership choices are made sequentially under perfect information.

0.5. With these parameters, $\bar{c}(p, n_i)$ varies as $\bar{c}(p = 0.5, n_i = 2) = 3{,}840$, $\bar{c}(p = 0.5, n_i = 3) = 4{,}320$, $\bar{c}(p = 0.5, n_i = 4) = 3{,}840$, and $\bar{c}(p = 0.5, n_i = 5) = 2{,}400$. These parameters satisfy (8) for all $n_i < n$. Hence, outsiders are deterred from encroachment if insiders invest in monitoring. Figure 2 shows how the stable coalition size varies with marginal monitoring cost c.

In the first panel of Figure 2, $c = 2{,}200$, which is always lower than $\bar{c}(p = 0.5, n_i)$. Therefore, insiders always find it advantageous to monitor and therefore deter the outsiders. In the first panel of Figure 2, we see that a coalition insider's payoff is always higher than an outsider's so the grand coalition ($n = 6$) is the unique stable coalition. The reason is that condition (19) is satisfied with $c = 2{,}200$, so according to Proposition 2, the grand coalition is the unique equilibrium coalition. In contrast, c is always higher than $\bar{c}(p = 0.5, n_i)$ in the third panel of Figure 2. Hence, insiders never invest in monitoring and outsiders are never deterred. According to Proposition 1, the unique equilibrium coalition size in this case is the smallest profitable coalition. Substituting the parameters in (17) and (18) we obtain $n_i^{nd} = \min\{n_i | n_i \geq 2.66\} = 3$. Therefore, the unique coalition size in this case is 3.

The second panel of Figure 2 illustrates an intermediate case. In this case c is lower than $\bar{c}(p = 0.5, n_i)$ except when the coalition size is $n_i = 5$. At this size, insiders will not invest in monitoring to deter the outsiders, but smaller coalitions will invest in monitoring. We observe in the second panel of Figure 2 that an outsider's payoff at $n_i = 5$ is higher than an insider's payoff at the grand coalition. Therefore, $n_i = 5$ is externally stable. Moreover, because insiders find it advantageous to deter the outsiders at $n_i = 4$, an insider's payoff at $n_i = 5$ is higher than an outsider's payoff at $n_i = 4$. Hence, $n_i = 5$ is also internally stable and, therefore, it is a stable coalition size. Note that $n_i = 5$ is also unique because coalition sizes $n_i = [2,3,4]$ are not externally stable and the grand coalition is not internally stable.

4. Experimental Design, Prediction and Procedures

To test the implications of the theoretical model, we conducted a series of lab-in-the-field experiments with members of TURFs in central and south-central Chile. We replicated these experiments with students from Universidad de Talca in Chile.

4.1 Experimental design and treatments

The experiments were framed as the decision to form coalitions that have rights to harvest *loco* (Chilean abalone). The basic structure of the experiment was based on the theoretical model presented on Section 3; however, we did not refer to groups as insiders and outsiders. Instead, the decision to join the coalition was described as a decision to join the blue group. Communication was never allowed within or between groups. The following parameters, which were used in the simulations in subsection 3.4, were common to all treatments. The number of participants in each experiment was $n = 6$. Each participant had an endowment of $x = 1$ day. Participants received $a = 1{,}760$ Chilean pesos if they spent all day harvesting *loco*, and $w = 320$ Chilean pesos if they spent all day outside the *loco* fishery in another activity. The marginal externality (congestion) cost was $d = 240$ Chilean pesos. Each participant received a fixed payment of $T = 400$ Chilean pesos and members of the blue group received additional $s = 400$ Chilean pesos. Note that $a - w - d = 1{,}200 > 0$, which implies that each individual would spend all of their time endowment harvesting *loco* if a coalition did not form. Moreover, the experiment parameters satisfy our theoretical assumptions that $a - d > w + 2s$ and $a - w - dn = 0$. We conducted the following five treatments.

- **T1. Open-access (OA):** In this treatment, coalition formation was not possible so subjects played a simple open-access game. The main purpose of this treatment was to provide a baseline to compare how the ability to form coalitions in the other treatments produced results that diverged from an open-access situation.

- **T2. No Enforcement (NE):** Coalition formation was allowed in this treatment, but insiders could not monitor the outsiders. This treatment allows us to determine whether coalitions will form when coalition members cannot deter poaching from outsiders. Moreover, comparing the results from this treatment with the remaining treatments, in which insiders could invest in monitoring, allows us to investigate how co-enforcement affects the formation of coalitions.

- **T3. Imperfect Monitoring/Low Cost (IM/LC):** In this treatment, coalition formation was allowed and, if a coalition formed, its members could choose to invest in monitoring via a majority-rule vote. The monitoring technology allowed the monitoring of each outsider with probability $p = 0.5$ at a marginal cost of $c = 2{,}200$. The total cost to a coalition if they chose to invest in monitoring was $cp = 1{,}100$. The fine for outsiders caught poaching the resource for a day was $f = 1{,}280$; thus, the expected fine was $pf = 640$.

- **T4. Imperfect Monitoring/High Cost (IM/HC):** This treatment had the same structure as IM/LC, but the parameters associated with monitoring and enforcement differed. The marginal cost of establishing $p = 0.5$ was increased to $c = 4{,}800$, so that the total cost to a coalition of investing in monitoring was $cp = 2{,}400$. The fine for poaching, as well as the expected fine, remained the same as in IM/LC. Comparing IM/HC with IM/LC allows us to investigate how a higher defense cost affects coalition formation.
- **T5. Perfect Monitoring/High Cost (PM/HC):** This treatment was the same as IM/LC except that if the insiders invested in monitoring, outsiders were observed perfectly; that is, $p = 1$. The marginal monitoring cost was again $c = 2{,}200$, but the total cost of monitoring for a coalition was $cp = 2{,}200$. The marginal poaching fine was reduced to $f = 640$, but the expected fine remained at $pf = 640$. The main purpose of this treatment is to compare outcomes with imperfect ($p = 0.5$) and perfect monitoring ($p = 1$), holding the marginal cost of monitoring and the marginal expected poaching fine constant.

4.2 Theoretical predictions

Table 2 contains the theoretical predictions associated with each of our treatments, several of which we have already presented in the simulations contained in Figure 2. These predictions form the hypotheses to be tested. Since OA is a standard linear open-access resource game, each subject uses all of their time harvesting the resource. NE, in which coalitions can form but poachers cannot be deterred, produces the same outcomes as when insiders can invest in monitoring but they choose not to. Thus, the payoff functions for insiders and outsiders are the same as those in the third panel of Figure 2. Recall in this case that the smallest profitable coalition size, $n_i = 3$, is the unique stable coalition size. Each of the coalition members restrict their time harvesting to 50% by design, while each of the outsiders choose to spend all of their time poaching the resource. Because the insiders restrict their exploitation of the resource, each harvester earns more than in the open-access equilibrium, while the free-riding outsiders earn substantially more than the insiders.

The payoff functions for IM/LC are graphed in the first panel of Figure 2. Recall that in this case that insiders always find it advantageous to invest in monitoring, any outsider would be deterred from poaching, and hence, the grand coalition is the unique stable coalition. Cooperation by all harvesters produces lower harvests and higher earnings relative to the open-access equilibrium and when a coalition can form but its members cannot deter the outsiders.

The payoff functions for IM/HC are graphed in the third panel of Figure 2. In this treatment, the cost of monitoring is so high that coalitions are never motivated to invest in the monitoring technology. Thus, the equilibrium outcomes in this treatment are the same as in NE in which monitoring is simply not possible. Likewise, while outsiders would be monitored perfectly in PM/HC, the cost of employing the technology that allows perfect monitoring is too high to be worthwhile for any coalition size. Once again, then, the equilibrium outcomes in PM/HC are the same as in NE.

In summary, coalitions should always form when it is allowed (under NE, IM/LC, IM/HC, and PM/HC). Given that a coalition forms under IM/LC, insiders will always invest in monitoring if the coalition is smaller than the grand coalition. In this case, outsiders will not poach the resource. However, we expect the grand coalition to form in this treatment, in which case there would be no need to invest in monitoring because there are no outsiders. Coalitions will never invest in deterrence when monitoring is too expensive in IM/HC and PM/HC. The ability to form coalitions will always lead to lower exploitation and higher earnings relative to the open-access situation, and these effects will be strongest when the cost of monitoring is low enough (i.e., in treatment IM/LC).

4.3 Procedures

The experiments were conducted with members of the Chilean TURF program for near-shore fisheries in central and southern Chile. Specifically, we conducted the experiments in the Maule, Bio-Bio and Los Lagos regions in the following communities: Amortajado, Arauco, Carelmapu, Cerro Verde, Chome, Coliumo, Illoca, La Arena, La Pasada, Llico, Lota Bajo, Maule, Maullin, Metre, Pellines, Perone, Putu and Tubul. We selected fisher unions for which *loco* was one of their principal targeted species. We block randomized the treatments to avoid concentrating treatments in specific communities and to have a reasonably balanced number of treatments across regions. Although participants had a variety of jobs in their unions, we will refer to them all as fishers throughout. A total of 258 fishers participated in our field experiments. Table 3 contains a summary of the number of groups and individuals who participated in our field experiments (fisher sample) by region.[7] We replicated the experiments with 228 students from Universidad de Talca, located in the Maule region in central Chile. A summary of the number of participants and groups by treatments is presented in Table 4.

Upon arrival at an experimental session, participants signed informed consent forms. The experimenter then read the instructions aloud with a PowerPoint presentation containing key aspects of the instructions.[8] Each participant received the same payoff table, which showed their payoff conditional on total time harvesting the resource, monitoring and their individual harvest decision. The payoff table differed among treatments. When coalition formation was allowed, the payoff table included two sections, one for coalition members and one for nonmembers. We used equations (1), (5) and (6) to compute the payoffs. Payoff tables were also projected on a screen during the entire session. At the end of each round the session leader used the tables projected on the screen to help participants determine their payoffs for the round. We ran the experiments with pen and paper. We conducted two practice rounds to familiarize participants with the rules, but we did not count these rounds in determining subjects' final payments. We asked control questions before beginning a data session to make sure the subjects were ready to participate in the experiments. We maximized the space between participants to allow them to work in private.

Each session consisted of 15 independent rounds or periods. Communication among subjects was never allowed. The baseline treatment OA consisted of just one stage, a "harvesting stage". In each round of this treatment participants chose to spend the whole day harvesting *loco*, the whole day earning money outside the *loco* fishery, or half the day harvesting *loco*s and the other half outside the fishery. Subjects wrote down their decisions in private. The aggregate time spent harvesting for the group was announced at the end of each round.

In the other four treatments, each round started with the "membership stage". In this stage each subject decided whether to join the blue group. Subjects made this decision in a predetermined random sequence under perfect information. At least two individuals had to join a blue coalition for one to form. The reason for this requirement is that the language used in the experiments was that individuals had the opportunity to join a "group" (*grupo*), and the common understanding of

[7] We divided the Biobio region in two geographical sub-regions (north and south). Communities in the north are part of the Greater Concepcion metropolitan area, the second largest in Chile after Greater Santiago. In contrast, communities in the south are in more sparsely populated rural areas.

[8] Experiment instructions (both English and Spanish), and the accompanying PowerPoint slides, are available as an online supplement at https://osf.io/s4pcm.

a group is that it contains more than one individual. If a coalition formed, then in the harvesting stage, non-members (outsiders) chose between spending all or none of their time endowment (one day) in the fishery. Coalition members (insiders) did not have a harvesting choice at this stage, because the requirement of joining the coalition was to spend half of their time harvesting. If a coalition did not form, then all participants played an open-access harvest game. This harvesting stage differs from the Open Access (OA) treatment in that participants were limited to choosing between spending all their time harvesting *loco* or all their time earning money outside the fishery. The No Enforcement (NE) treatment consisted of the membership and harvesting stages. The round ended after the harvesting stage and the aggregate time spent harvesting was announced to the group.

The three co-enforcement treatments, IM/LC, IM/HC and PM/HC, followed the timeline in Figure 1. If a coalition formed at the membership stage in these treatments, members of the blue group then decided whether to invest as a group in a monitoring technology at the "monitoring investment" stage. The total cost of the monitoring technology was 1,100 Chilean pesos in IM/LC, 2,400 Chilean pesos in IM/HC, and 2,200 Chilean pesos in PM/HC. This cost was divided equally among the members of the blue coalition. The coalition made its monitoring decision by majority-rule. Individual votes were cast simultaneously and independently without prior communication. In case of a tie a coin was flipped to decide the outcome. The blue group's monitoring decision was announced at the end of the monitoring investment stage. The outsiders were aware of the monitoring decision before they made their harvest decision.

The harvesting stage in treatment IM/LC, IM/HC and PM/HC was the same as in the No Enforcement treatment (NE). The aggregate time spent harvesting for the group was announced at the end of this stage. If the blue group did not invest in monitoring, then the round ended at this stage. If the blue group did invest in monitoring the round proceeded to the enforcement stage. In the imperfect monitoring treatments, IM/LC and IM/HC, each subject who did not join the blue group flipped a coin to determine whether they would be monitored. Each participant who did not join the blue group was monitored in the perfect monitoring treatment PM/HC. If an outsider was monitored and was found to have chosen to spend all their time harvesting *loco*s, they paid a fine of 1,280 Chilean pesos in IM/LC and PM/HC, and 640 Chilean pesos in PM/HC.

Each session lasted about 90 minutes. Participants were paid their cumulative earnings in cash at the end of a session. Fishers received 13,586 Chilean pesos ($\sigma = 2{,}538$) on average, with a range of 3,040 to 17,440. Students received 12,618 Chilean pesos ($\sigma = 1{,}059$) on average, with a range of 9,680 to 16,200. Additionally, each participant was paid a show-up fee of 2,500 Chilean pesos. At the time of the experiments the average exchange rate was about 606 Chilean pesos to one US dollar. At the end of each session we conducted a survey to collect socioeconomic information as well as the fisher's perceptions regarding poaching activity and enforcement actions in their management area.

4.4 Field experiment participant characteristics

Summary statistics of participant characteristics are presented in Table 5. Fishers were mostly male (67%). Their mean age was about 49 years old (σ = 13.4) with about 8.2 years of formal schooling (σ = 3.42). On average, they were members of their fishing organizations for 16.9 years (σ = 10.2) and they lived in the same fishing village (caleta or cove) for 43.2 years (σ = 15.3). Many of the fishers were heads of household (73.6%). Mean monthly family income was about 280,000 Chilean pesos (about US$ 462 in January 2018); only 13% of participants had monthly incomes above 450,000 Chilean pesos (about US$ 742). The fishers' main activity in their fishing organization was: fishermen/crew members (21%), divers (20%), boat owners (13%), shellfish gatherers (10%), and seaweed collectors (22%). The remaining 14% reported that they were boat operators, assistants to divers, administrators, and other. Most of the student participants were female (66%). The mean age was 21 years old (σ = 2.1) with about 15.5 years of formal schooling (σ = 1.6). Most of student participants were majoring in economics and business administration (22.4%). Only 7.4% of the students had experience in the fishing industry, and only 1.3% had experience either in the Chilean TURF program or in the *loco* fishery, or both.

Fishers reported that being part of their fishing organization was important for their marine-related work. The mean response on a scale of from 1 to 10 from "not important" to "really important" was 8.9. We asked a related question to students about how important it was for them to form groups in their everyday life. Their mean response on a scale of from 1 to 10 from "not important" to "really important" was 8.2. Fishers reported that the problem of poaching *loco* in their management area was important. The mean response on a scale from 1 to 10 from "problem is irrelevant" to "problem is very relevant" was 8.3. As for who is responsible for monitoring and enforcement to deter poaching, approximately 66% of participants believed that both fishers' organization and the government have the responsibility. Most of the participants reported that members of their fishing organization patrol their area instead of contracting outside the organization. 77% of the participants reported that their area is actively monitored by their organization, and they reported that this activity is risky. The mean response on a scale from 1 to 10 from “patrolling is not risky” to “patrolling is highly risky” was 7.1. The mean response on a scale from 1 to 10 that monitoring efforts by their organization were “ineffective” to “very effective” was 6.9.

Regarding the participation of government authority’s participation in deterring poaching, fishers perceived that the monitoring efforts of the Navy were not very effective. The mean response on a scale from 1 to 10 that patrolling by the government is “ineffective” to “very effective” was 4.9. We also asked the participants what happens to poachers when they are caught poaching in the area: 58.3% of the participants responded that poachers would be reported to the authorities and sanctioned; 35.8% responded that poachers would be reported to the authorities but would not be sanctioned; and 5.9% responded that nothing would happen. These survey results diverge somewhat from those reported in Chávez, et al. (2018). In their study, a lower mean response score (3.2) was obtained regarding the effectiveness of the Navy in deterring poaching, and 50% of the participants responded that poachers would be reported to the authorities but would not be sanctioned. These differences may be because the experiments of Chávez, et al. (2018) were conducted in the Biobio region, while in our case we also have fishers’ organizations from the Maule and Los Lagos regions.

5. Results[9]

In this section we present the results of the field experiments with fishers, and conclude with a brief discussion of how the results with fishers compare with those of the university students. We focus our presentation on the following outcome variables: coalition formation, coalition size, insider investments in monitoring, total time spent harvesting by the group (insiders and outsiders combined), poaching by individual outsiders, and individual earnings. We begin in section 5.1 by describing the models used for each outcome variable. For conciseness, the regression results are provided in the online supplement (Tables B-1 to B-7 for the field experiments, and Tables C-1 to

[9] Data, statistical code and detailed regression results are available as an online supplement at https://osf.io/s4pcm/.

C-7 for the lab replication). For each outcome variable, we estimated three models. Model 1 only includes treatment effects. Model 2 adds Period to control for possible learning or other dynamic effects. Model 3 adds participant characteristics, defined as the within-group average of individual characteristics. The online supplement contains additional details from the regression results, including estimated values for each treatment, tests of treatment differences, and tests of point predictions. Figures 3 through 9 present estimated means and 95% confidence intervals for the fishers using Model 1 of the related table. In each figure, the red squares indicate the equilibrium outcomes from Table 2. In section 5.2, the discussion of results from the fishers is organized by treatment. We briefly discuss the student results in section 5.3.

5.1 Model descriptions

Coalition formation and coalition size. Table B-1 and Figure 3 present the results from a random effects probit model that estimates the probability a coalition forms. The units of observation are groups in rounds (15 observations per group). Because subjects were not able to form coalitions in the baseline Open Access (OA) treatment, we used No Enforcement (NE) as the omitted treatment. Since fishers always formed coalitions in Imperfect Monitoring-Low Cost (IM/LC) treatment we omitted this treatment from the estimation. Nevertheless, since the probability of coalition formation is one in IM/LC treatment, we can compare it with the estimated coalition formation probabilities in the other treatments. Table B-2 and Figure 4 follow a similar structure to present the results of a linear random effects model estimating the coalition size, conditional on coalition formation.[10]

Collective Monitoring by Insiders. Table B-3 and Figure 5 present the results of a random effects probit model of the coalitions' collective decision (via majority vote) to invest in monitoring each round. We restricted the data to rounds in which monitoring was available (i.e. coalitions formed with $n_i < 6$; OA and NE treatments excluded). IM/LC was defined as the base treatment.

Total time spent harvesting. The overall impact of coalition formation on the resource can be measured by the total amount of time spent harvesting in a round by insiders and outsiders

[10] We also estimated a two-part hurdle model in which we first used a probit to estimate the probability of coalition formation, and then estimated a truncated linear model for coalition size. Results are qualitatively the same.

combined. This provides insights into how changes in monitoring and enforcement affect the resource. Table B-4 presents a linear random effects model that includes interaction terms between treatments and a dummy variable for coalition formation. OA is the base in this model. Figure 6 presents averages for total time spent harvesting per round.

Individual poaching by outsiders. Table B-5 and Figure 7 present results of a random effects probit model of the individual-level decision to poach by the outsiders. Unlike the previous models, the unit of observation is the individual in a round, rather than the group outcome. We restricted the analysis to consider only rounds in which a coalition formed with $n_i < 6$ members.[11] Monitoring was not allowed in the no-enforcement treatment NE or the open access baseline OA, therefore these treatments are not included. Estimated probabilities and hypothesis tests are presented both for those rounds in which the insiders voted to monitor and for those rounds in which monitoring was not implemented.

Individual earnings. Table B-6 and Figure 8 present results of a linear random effects model of individual earnings per round (includes both insiders and outsiders combined). As with the aforementioned poaching model, the unit of observation is an individual in a round. The model includes an interaction with a variable that indicates whether a coalition formed. Table B-7 and Figure 9 follow a similar approach to estimate individual earnings separately for insiders and outsiders, conditional on coalition formation.[12]

5.2 Field experiment results discussion

Hypotheses were tested with the regression analyses in the online supplement Tables B-1 to B-7; *p*-values discussed below are from Model 1, the other models yield similar conclusions. Overall, our results indicate that fishers formed coalitions quite frequently, even when they could not deter outsider poaching (NE) or monitoring was very costly (IM/HC and PM/HC). When the cost of monitoring was low (IM/LC), fishers formed coalitions on average that were close to the grand coalition as predicted. Coalition sizes were smaller when monitoring was not available or very costly.

[11] We also considered whether being monitored in the previous period had a significant effect on an outsider's decision to poach; it did not.
[12] The regression model in Table B-7 includes data from the OA treatment even though coalition formation was not possible. For purposes of this regression only, we assumed that a coalition always formed in this treatment to facilitate comparison of earnings for insiders in the other treatments.

Open Access (OA). This treatment serves as a baseline in which group members could not form a coalition and there was no monitoring. In theory, each of the 6 group members should choose to harvest one unit, leading to overexploitation of the resource and individual earnings of 720 (Table 2). Average outcomes were close to these benchmarks, with a 5 unit mean total harvest time by the group (Figure 6), resulting in average individual earnings of 805 (Figure 8).

No Enforcement (NE). The decision to join the coalition includes a binding commitment to reduce individual harvest by 50%, thereby conserving the resource. In theory, a small coalition should form with three members who earn slightly more than they would under open access from total harvest time of 4.5 by insiders and outsiders combined (Table 2). Results in Figure 3 show that, consistent with equilibrium predictions, coalitions formed the overwhelming majority (85%) of the time. Given coalition formation, there was no statistically significant difference between the mean coalition size (3.49) and the 3-person minimum profitable coalition (p=0.251). When coalitions formed, mean harvests by insiders and outsiders combined (4.1, Figure 6) were consistent with equilibrium predictions (p=0.044). These results suggest that even without the ability to deter poaching, coalitions can form and limit harvests to exert less pressure on the resource. When coalitions formed, average earnings for insiders (897, Figure 9) were slightly higher than under open access (805), while outsiders earned significantly more (1088). As expected, in those few instances when a coalition did not form, total time harvesting (Figure 6) and individual earnings (Figure 8) were comparable to OA.

Imperfect Monitoring / Low Cost (IM/LC). In this treatment, outcomes were generally consistent with theoretical predictions. When coalition formation is possible and monitoring costs are low, the coalition size should increase to the grand coalition, with $n_i = 6$. A coalition did form in every group in every round, and the grand coalition formed 64% of the time. As hypothesized, the mean coalition size with low monitoring costs (5.44, Figure 4) was larger than in NE (3.49). When the grand coalition did not form, monitoring was implemented 94% of the time (Figure 5), and we fail to reject the null hypothesis that this equals the equilibrium prediction of 100% (p=0.307). This frequent monitoring discouraged poaching relative to NE, but did not fully eliminate it (Figure 7). The combined harvest time of insiders and outsiders (3.1, Figure 6) equaled the 3-unit theoretical prediction (p=0.109). Insider earnings were slightly below the theoretical prediction (Figure 9), and substantially higher than under *Open Access*.

High Cost Monitoring (both IM/HC and PM/HC). The experiments were parameterized such that the high cost would make monitoring too expensive, leading to the same outcomes as NE, and this is generally what we observe, with one noteworthy exception. Figure 3 shows that coalitions did form at rates similar to NE (91% in IM/HC and 82% in PM/HC). We fail to reject the hypothesis that the probability of coalition formation in each treatment equals that of NE, and a test of the hypothesis that these two high monitoring cost treatments are jointly equal to NE cannot be rejected (p=0.603). Figure 4 shows that, while the mean coalition size increased by about one person relative to NE, this increase is not significant. Moreover, we fail to reject the joint hypothesis that coalition size in all three treatments is equal (p=0.169).

However, in both high cost treatments, Figure 5 shows that coalitions frequently voted to invest in monitoring even though, in theory, it was not profitable to do so. When a coalition formed, the probability that insiders voted to invest in monitoring was similar between the two high cost treatments (p=0.121). Outsiders were aware that the insiders invested in monitoring, despite incentives to the contrary, and as a result, poaching was lower relative to those instances without monitoring (Figure 7). Compared to NE, insider investments in monitoring and the resulting reduction in poaching led to lower overall harvests by insiders and outsiders combined (Figure 6). Conditional on coalition formation, insider earnings in the two high monitoring cost treatments were not significantly different from average earnings in the Open Access (OA) and No Enforcement (NE) treatments (Figure 9). We fail to reject the joint hypothesis that insider earnings in those four treatments are jointly equal (p=0.23). Outsider earnings were lower than NE due to the penalties incurred for poaching, and comparable to earnings OA.

5.3 University student experiment results

Data analysis from the lab experiments with students from Universidad de Talca in Chile uses the same approach as previously described for the fishers. A summary of the student results is provided in Table 6. Elements in the table are predicted outcomes from regression models described in subsection 5.1 applied to the student sample. These regressions are provided in the online supplement (Tables C-1 through C-7). All significance tests discussed below are also from these models. Related figures for the student sample, similar to Figures 3 through 9 for the fishers, are also in the online supplement (Figures C-1 through C-7).

The results from the lab experiments with university students are very different from the field experiments with fishers. First, the students did not form coalitions as frequently as the fishers. Table 6 shows that the predicted probabilities of coalition formation for the students range between 0.49 and 0.72, whereas the corresponding range for the fishers is 0.82 to 1.0. Moreover, when the students did form coalitions they tended to be smaller. Note from Table 6 that coalition sizes for the students were less than three members for each coalition-formation treatment, while for the fishers the coalition sizes were significantly greater than three members in the IM/HC and PM/HC treatments and approached the grand coalition size of six members under the IM/LC treatment (Figure 4). Note also that the student coalitions did not invest in monitoring very often in the enforcement treatments, IM/LC, IM/HC and PM/HC. Coalitions of fishers, in contrast, very frequently invested in monitoring (Figure 5). While coalition formation tended to reduce total harvest time and monitoring reduced encroachment, the combination of small coalitions, low investments in monitoring and high levels of encroachment led to low earnings for student insiders. In fact, average earnings for student coalition members were significantly lower under the NE, IM/HC and PM/HC treatments than they were under open access; average earnings under the IM/LC treatment were also lower than open access, but not significantly so.

It is possible that the greater coalition formation and willingness to invest in monitoring that we observe from fishers relative to the university students is related to the fishers' participation in organizations that hold area-based fishing rights and consequently work together to restrain harvests and protect their resources. In addition, Chilean fishing organizations tend to be community based, which may imply that the fishers work together on local issues apart from the near-shore fishery. Thus, our results are consistent with those from a literature that uses economic experiments to investigate whether norms of cooperation and pro-sociality can emerge from workplace organizations that rely on these norms. For example, Gneezy et al. (2016) found that fishers in Brazil who worked together were significantly more cooperative in a suite of social dilemma experiments than nearby fishers who worked alone. Similarly, Leibbrandt et al. (2013) found that Brazilian fishers who worked alone were more competitive than fishers who worked together. With CPR experiments conducted with near-shore fishers in Chile, Gelcich et al. (2013) found that members of fishing unions showed significant levels of cooperation, while fishers who did not belong to a fishing union did not cooperate at all. While the greater cooperation exhibited by fishers in our experiments may be due the existence of norms they have developed working together in their fishing organizations, lower levels of cooperation and pro-sociality by students have also been noted in a large number of experiments involving students and nonstudents (Anderson, et al., 2013; Belot, et al., 2015; Carpenter, et al., 2008; Falk, et al., 2013).

6. Conclusions

In this paper we have presented the results of a framed field experiment where we consider the problem of managing and defending the commons when CPR coalitions form endogenously. Our theoretical model predicts that the grand coalition will be stable and unique when the cost of monitoring is low. However, when insiders are not able to monitor for poaching, or the cost is so high that monitoring is not worthwhile, the equilibrium coalition is the smallest profitable coalition. These predictions are largely supported by our experimental results for fishers that belong to organizations that operate under the Chilean TURF system. When the cost of monitoring was low, fishers formed coalitions on average that were close to the grand coalition. Coalition sizes were significantly smaller when monitoring was not available or very costly, but they were larger than the minimum profitable coalition size. In general, the ability of fishers to form coalitions reduced exploitation of the resource in comparison to the open access outcome. On the other hand, students did not form large coalitions when the cost of monitoring outsiders was low. Coalition sizes were very close to the minimum profitable coalition size when monitoring was not available and when it was very costly. In several treatments, student coalition members were worse off than under the open-access situation.

Our results have important implications for the design of area-based property rights policies, such as territorial use rights for fisheries, community land titles and community forests. CPR coalitions can form endogenously under favorable institutional and legal conditions that enable CPR users to claim sole responsibility for a resource and to work with government authorities to prevent encroachment by outsiders. Our results from the student subject pool suggest that social conditions must be favorable for CPR coalitions to form as well. CPR coalitions are more likely to form when a measure of trust and social cohesion are already present, which, in turn, may come from long local experience with the resource.

The ability to deter outsiders at reasonable cost positively affects the size of CPR coalitions, their management and defense of the resource, profitability, sustainability and resilience. When outsiders cannot be deterred—perhaps for technological, geographical or economic reasons—

coalitions may form but they will be small and not very profitable. Theoretically, these small coalitions are stable, but in fact they are also fragile in the sense that one defection can cause the coalition to collapse. Members of these small CPR coalitions are barely better off than under open access, and hence, these groups are probably not as sustainable or resilient as larger, more inclusive groups. However, when deterrence is possible at reasonable cost, our theoretical and experimental results suggest that CPR coalitions can be larger, more inclusive, and more profitable.

In addition to enabling the formation of CPR coalitions, government authorities may also aid in the defense of CPR boundaries to help make CPR coalitions more inclusive and profitable. These actions can include implementing appropriate encroachment sanctions and establishing more effective protocols for prosecuting and penalizing encroachers. Government authorities can also make their own contributions to monitoring for encroachment. Contributions that would complement user efforts might be most effective. That is, contributions of monitoring technologies (searchlights, radar, night vision goggles, etc.) that significantly increase the effectiveness of coalition members' monitoring efforts might be more effective than contributions like extra patrols that may be substitutes for their efforts. Moreover, policies that facilitate coordination between different CPR coalitions in a given region may also improve monitoring efforts. This coordination might include region-wide public meetings to discuss monitoring strategies, or providing monitoring technologies that facilitate coordination and communication across groups (e.g., radio equipment, satellite phones to be used in isolated locations, internet connection, etc.).

Finally, while this paper has focused on how the difficulty of deterring encroachment affects the formation of CPR coalitions, there are other fundamental elements of the problem that deserve future research. These include, for example, the ability to limit membership by coalition members, exclusion risks, and the value of outside options. In general, improving our understanding of the decentralized formation of coalitions to manage and defend CPRs will be useful for creating policies for the legal establishment of collective property rights and the appropriate role of government agencies in promoting the efficient and sustainable use of natural resources.

7. References

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8. Appendix

Proof of Proposition 1: Stable coalitions must be profitable in the sense that coalition members are at least as well off as if no coalition formed at all and individuals earned the open access payoff (3). The reason is that an unprofitable coalition cannot be internally stable. A profitable coalition when coalition members do not monitor outsiders is any $n_i \in (1, n]$ such that

$$b_i^{nd}(n_i) - b_{oa} \geq 0. \tag{A-1}$$

Substitute for $b_i^{nd}(n_i)$ from Table 1 and b_{oa} from (3) to obtain

$$b_i^{nd}(n_i) - b_{oa} = s - \frac{1}{2}(a - w - dn_i). \tag{A-2}$$

(The derivation of (A-2) requires use of the assumption $a - w - dn = 0$.) Solve $b_i^{nd}(n_i) - b_{oa} = 0$ for n_i to obtain n_i^0 given by (18). Rearrange (4) to obtain $(a - w - 2s)/d > 1$, which reveals $n_i^0 > 1$. In addition, note that $b_i^{nd}(n_i) - b_{oa}$ is strictly increasing in n_i; therefore, n_i^0 is unique and every coalition larger than n_i^0 is profitable. The smallest of these coalitions is n_i^{nd} given by (17). Moreover, $n_i^{nd} > 1$ because $n_i^0 > 1$.

We now demonstrate the internal and external stability of n_i^{nd}. This coalition size is internally stable because the open access outcome results if one person leaves the coalition, and $b_i^{nd}\left(n_i^{nd}\right) - b_{oa} \geq 0$. From (16), external stability of n_i^{nd} requires $b_0^{nd}\left(n_i^{nd}\right) - b_i^{nd}\left(n_i^{nd} + 1\right) \geq 0$. Using the functions in Table 1, calculate

$$b_0^{nd}\left(n_i^{nd}\right) - b_i^{nd}\left(n_i^{nd} + 1\right) = \frac{1}{2}(a - d - w) - s > 0. \tag{A-3}$$

The inequality of (A-3) follows from (4); hence, n_i^{nd} is externally stable.

To demonstrate that n_i^{nd} is the unique equilibrium coalition size when the insiders do not monitor the outsiders, first recall that coalition sizes smaller than n_i^{nd} are not internally stable because they are not profitable. Moreover, coalition sizes larger than n_i^{nd} are also not internally stable. To see this, from (15) note that internal stability of $n_i > n_i^{nd}$ requires $b_i^{nd}(n_i) - b_0^{nd}(n_i - 1) \geq 0$. ($b_0^{nd}(n_i - 1)$ is a profitable coalition because $n_i > n_i^{nd}$.) Using the functions in Table 1, calculate

$$b_i^{nd}(n_i) - b_0^{nd}(n_i - 1) = s - \frac{1}{2}(a - d - w) < 0 \tag{A-4}$$

The inequality follows because $(a - d - w)/2 - s > 0$ from (4), and shows that a coalition size $n_i > n_i^{nd}$ cannot be internally stable. Since no coalition size less than or greater than n_i^{nd} is internally stable, n_i^{nd} is the unique equilibrium coalition size when insiders do not monitor the outsiders.

To complete the proof we show that the equilibrium coalition when insiders cannot deter the outsiders is strictly less than the grand coalition. To see this note that (A-4) also holds for $n_i = n$, revealing that the grand coalition is not internally stable when smaller coalition cannot deter the outsiders.[13] QED.

Proof of Proposition 2: Recall from (14) that $c < d(n-1)/p$ implies that any coalition that forms will find it advantageous to deter the outsiders. To check for the internal stability of the grand coalition when this is true, note from (15) and Table 1 that internal stability of $n_i = n$ requires $b_i^d(n) - b_0^d \geq 0$. Using the assumption that $a - w - dn = 0$, calculate $b_i^d(n) - b_0^d = s > 0$. Therefore, the grand coalition is internally stable when any coalition would monitor outsiders. Now turn to external stability. Using (16) and Table 1, when any coalition would find it advantageous to monitor the outsiders, external stability requires $b_o^d \geq b_i^d(n_i + 1)$. Calculate

$$b_o^d - b_i^d(n_i+1) = -\left(s + \frac{1}{2}\big(a - w - d(n_i+1)\big) - \frac{cp}{(n_i+1)}\right),$$

which is greater than or equal to zero if and only if

$$c \geq \frac{(n_i+1)\big(2s + a - w - d(n_i+1)\big)}{2p}.$$

However, when (19) holds the inequality is reversed, which indicates that no coalition of size $n_i < n$ is externally stable. Since when (19) holds the grand coalition is internally stable and no other coalition size is externally stable, the grand coalition is the unique stable coalition. QED.

[13] Note from (A-4) that no coalition size $n_i < n$ is externally stable if s is high enough, because the motivation to freeride on the conservation efforts of others vanishes. In this case, the grand coalition is the unique stable coalition.

9. Tables

Table 1. Possible subgame equilibria given the formation of a coalition $n_i \in (1, n)$.

	$c \leq \bar{c}(p, n_i)$ (Deter)	$c > \bar{c}(p, n_i)$ (Not deter)
Poaching	$e_o = 0$	$e_o = 1$
Total time harvesting	$\frac{n_i}{2}$	$\frac{n_i}{2} + n_o = n - \frac{n_i}{2}$
Outsider payoffs	$b_0^d = T + w$	$b_0^{nd}(n_i) = T + a - d\left(n - \frac{n_i}{2}\right)$
Insider payoffs	$b_i^d(n_i) = T + \mathrm{s} + \frac{1}{2}(a + \ w - dn_i) - \frac{cp}{n_i}$	$b_i^{nd}(n_i) = T + s + \frac{1}{2}(a + \ w + dn_i) - dn$

Table 2. Theoretical predictions

Treatment	Monitoring	Coalition size	Total Time Harvesting			Individual Earnings		
			Insiders	Outsiders	Total	Insiders	Outsiders	Open-Access
T1. OA					6			720
T2. NE		3	1.5	3	4.5	760	1,080	
T3. IM/LC	Yes	6	3	0	3	1,120		
T4. IM/HC	No	3	1.5	3	4.5	760	1,080	
T5. PM/HC	No	3	1.5	3	4.5	760	1,080	

OA=Open Access treatment; NE=No Enforcement; IM/LC=Imperfect Monitoring/Low Cost; IM/HC=Imperfect Monitoring/High Cost; PM/HC=Perfect Monitoring/High Cost

Table 3. Number of fishers and participants per region

Region	Groups	Participants
Maule	8	48
Biobio - Norte	13	78
Biobio - Sur	12	72
Los Lagos	10	60
Total	43	258

Table 4. Number of groups and participants per treatment

Treatment	Fishers		Students	
	Groups	Participants	Groups	Participants
T1. OA	9	54	7	42
T2. NE	9	54	8	48
T3. IM/LC	8	48	8	48
T4. IM/HC	8	48	8	48
T5. PM/HC	9	54	7	42
Total	43	258	38	228

Notes: OA=Open Access treatment; NE=No Enforcement; IM/LC=Imperfect Monitoring/Low Cost; IM/HC=Imperfect Monitoring/High Cost; PM/HC=Perfect Monitoring/High Cost

Table 5. Descriptive statistics. Fisher and student samples.

Variable	Fishers					Students				
	N	Mean	Std. Dev	Min	Max	N	Mean	Std. Dev	Min	Max
Age	258	49.49	13.41	15	84	228	21.29	2.09	17	31
Education	258	8.20	3.42	0	16	228	15.53	1.57	13	18
% Male	258	0.67				228	0.34			
Years in union	253	16.96	10.21	1	60					
Years in community	255	43.22	15.31	3	84					

Table 6. University student results

Outcome	Treatments				
	OA	NE	IM/LC	IM/HC	PM/HC
Probability coalition forms		0.57	0.72	0.56	0.49
		(0.04)	(0.08)	(0.06)	(0.03)
Coalition size		2.39	2.87	2.56	2.51
		(0.08)	(0.13)	(0.08)	(0.06)
Probability groups invests in monitoring			0.40	0.16	0.20
			(0.05)	(0.03)	(0.05)
Group time harvesting when coalitions formed		4.78	3.70	4.23	4.18
		(0.04)	(0.14)	(0.11)	(0.16)
Group time harvesting when coalitions did not form	5.11	5.67	5.46	5.45	5.44
	(0.15)	(0.04)	(0.14)	(0.07)	(0.11)
Individual probability of poaching (no monitoring)		0.99	0.95	0.96	0.98
		(0.00)	(0.02)	(0.02)	(0.01)
Individual probability of poaching (monitoring)			0.40	0.36	0.28
			(0.06)	(0.09)	(0.09)
Outsider individual earnings when coalitions formed		998	930	955	961
		(6.9)	(18.8)	(15.4)	(15.4)
Insider individual earnings when coalitions formed		712	824	679	676
		(12.1)	(28.0)	(15.0)	(21.9)
Individual earnings when coalitions did not form	849	784	801	822	818
	(22.9)	(7.0)	(15.4)	(14.3)	(15.9)

Note: These are the estimated values from Model 1 in online supplement Tables C-1 to C-7. OA=Open Access treatment; NE=No Enforcement; IM/LC=Imperfect Monitoring/Low Cost; IM/HC=Imperfect Monitoring/High Cost; PM/HC=Perfect Monitoring/High Cost. Standard errors in parenthesis.

10. Figures

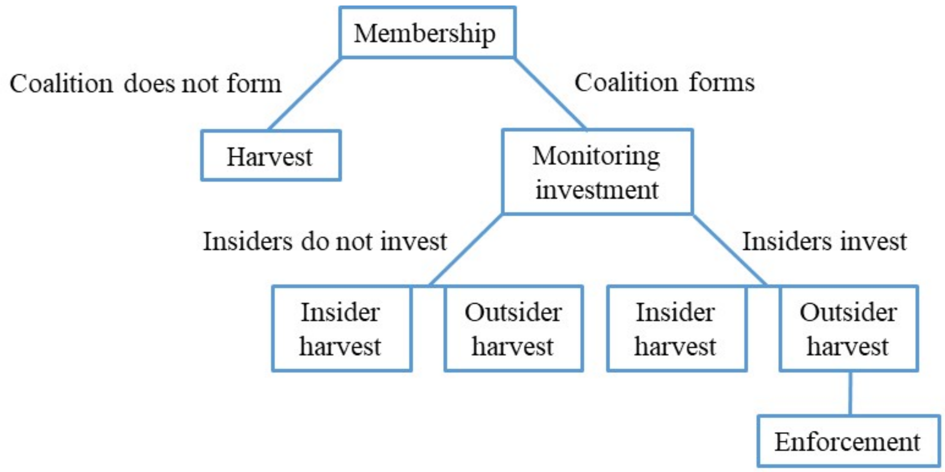

Figure 1. Stages of the coalition formation game

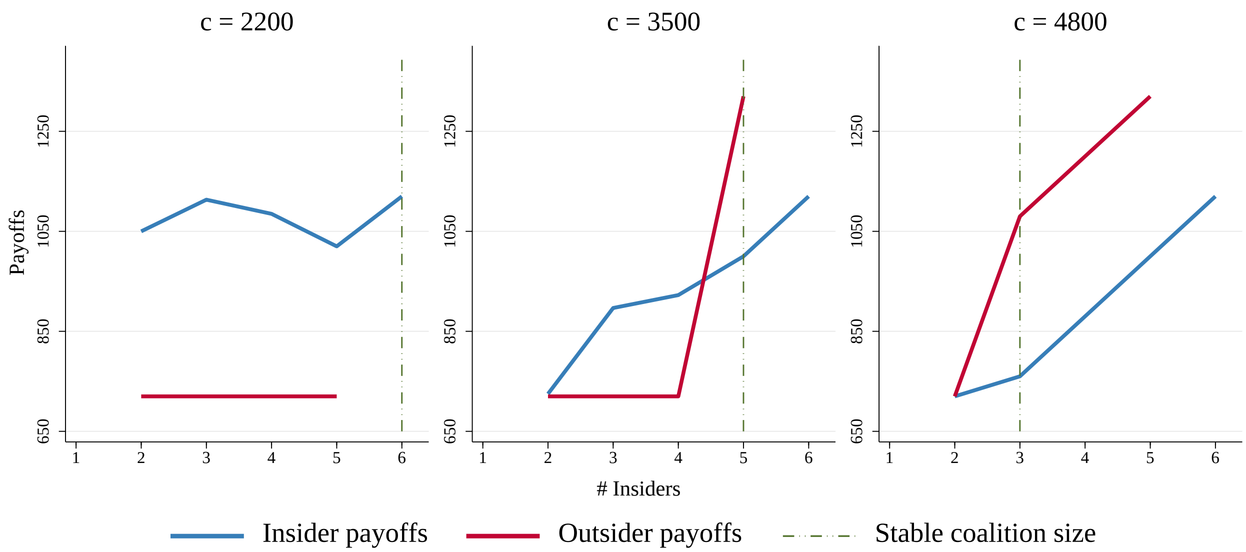

Figure 2. Individual payoffs and stable coalitions for alternative marginal monitoring costs.

Parameters: $n = 6,\ T = 400,\ a = 1{,}760, w = 320,\ d = 240,\ s = 400,\ f = 1{,}280,\ p = 0.5$

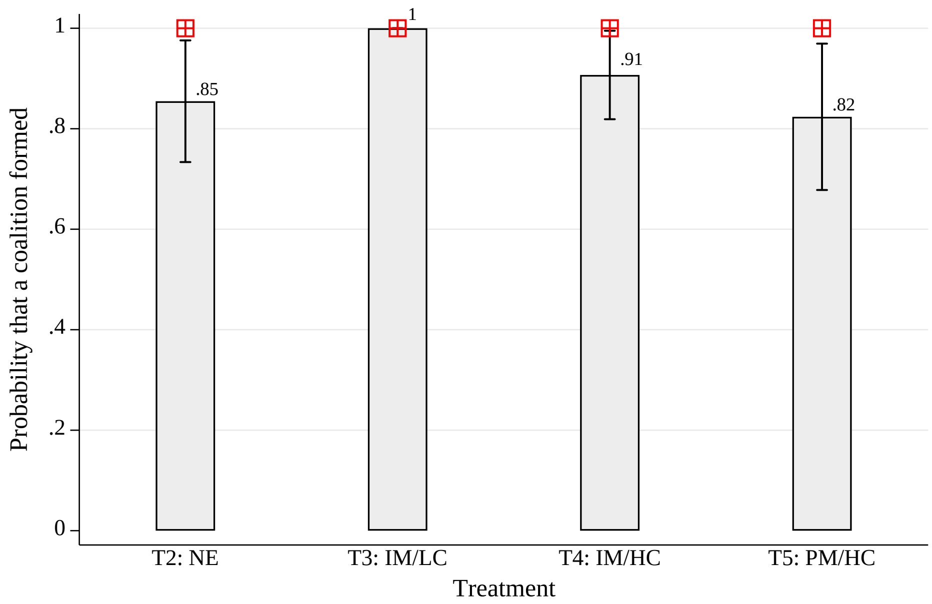

Figure 3. Probability that a coalition formed

Note: Estimated values from Model 1 in online supplement Table B-1. Red squares indicate equilibrium outcomes. Error bars indicate 95% confidence intervals. OA=Open Access treatment; NE=No Enforcement; IM/LC=Imperfect Monitoring/Low Cost; IM/HC=Imperfect Monitoring/High Cost; PM/HC=Perfect Monitoring/High Cost

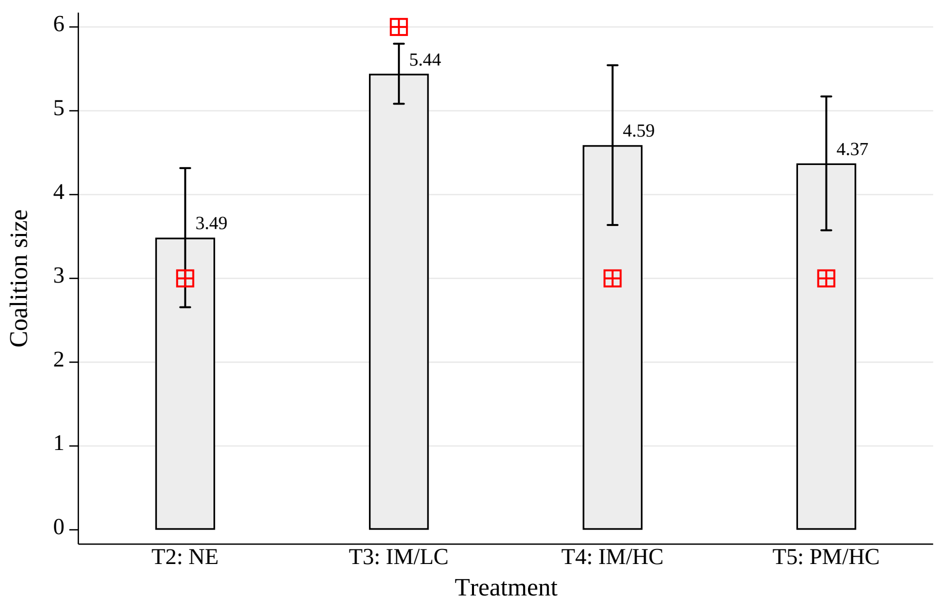

Figure 4. Coalition size, conditional on coalition formation.

Note: Estimated values from Model 1 in online supplement Table B-2. Data restricted to cases when a coalition was formed. Red squares indicate equilibrium outcomes. Error bars indicate 95% confidence intervals. OA=Open Access treatment; NE=No Enforcement; IM/LC=Imperfect Monitoring/Low Cost; IM/HC=Imperfect Monitoring/High Cost; PM/HC=Perfect Monitoring/High Cost

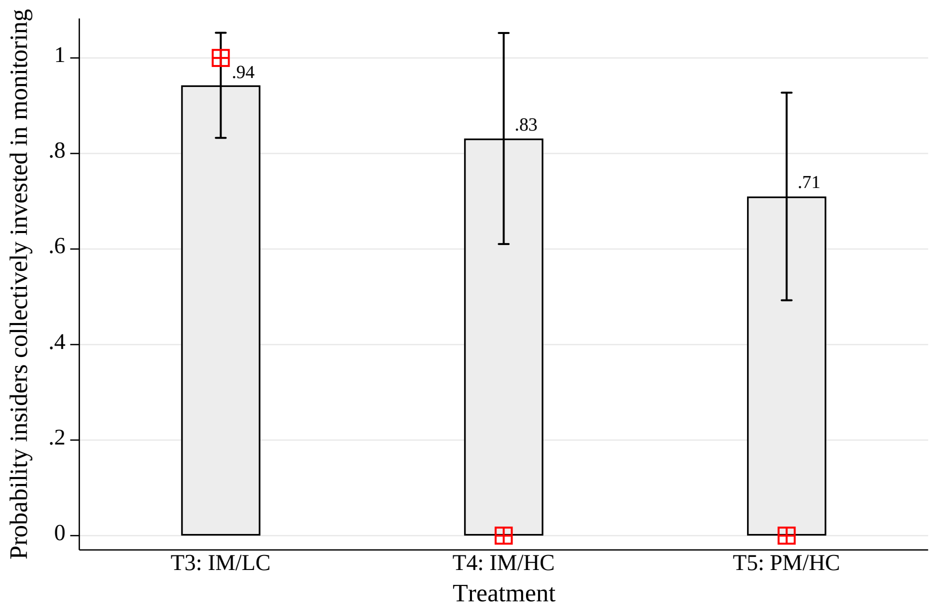

Figure 5. Probability insiders collectively invest in monitoring

Note: Estimated values from Model 1 in online supplement Table B-3. **Conditional on monitoring being available (i.e. a coalition forms with $n_i < 6$).** Red squares indicate equilibrium outcomes. Error bars indicate 95% confidence intervals. OA=Open Access treatment; NE=No Enforcement; IM/LC=Imperfect Monitoring/Low Cost; IM/HC=Imperfect Monitoring/High Cost; PM/HC=Perfect Monitoring/High Cost

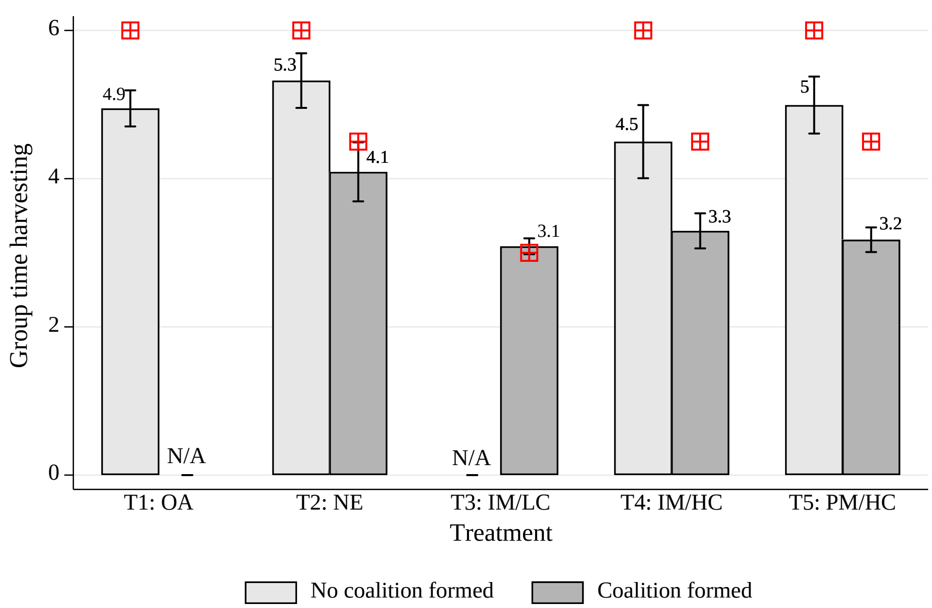

Figure 6. Total time harvesting per round (insiders + outsiders)

Note: Estimated values from Model 1 in online supplement Table B-4. Red squares indicate equilibrium outcomes. Error bars indicate 95% confidence intervals. OA=Open Access treatment; NE=No Enforcement; IM/LC=Imperfect Monitoring/Low Cost; IM/HC=Imperfect Monitoring/High Cost; PM/HC=Perfect Monitoring/High Cost

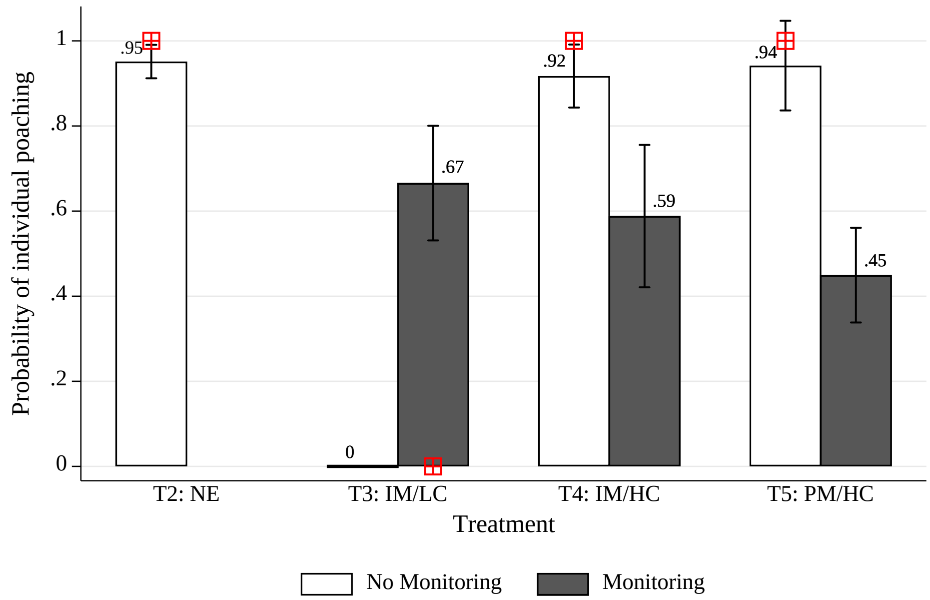

Figure 7. Probability of individual poaching

Note: Estimated values from Model 1 in online supplement Table B-5. **Conditional on coalitions forming with $n_i < 6$.** Red squares indicate equilibrium outcomes. Error bars indicate 95% confidence intervals. OA=Open Access treatment; NE=No Enforcement; IM/LC=Imperfect Monitoring/Low Cost; IM/HC=Imperfect Monitoring/High Cost; PM/HC=Perfect Monitoring/High Cost

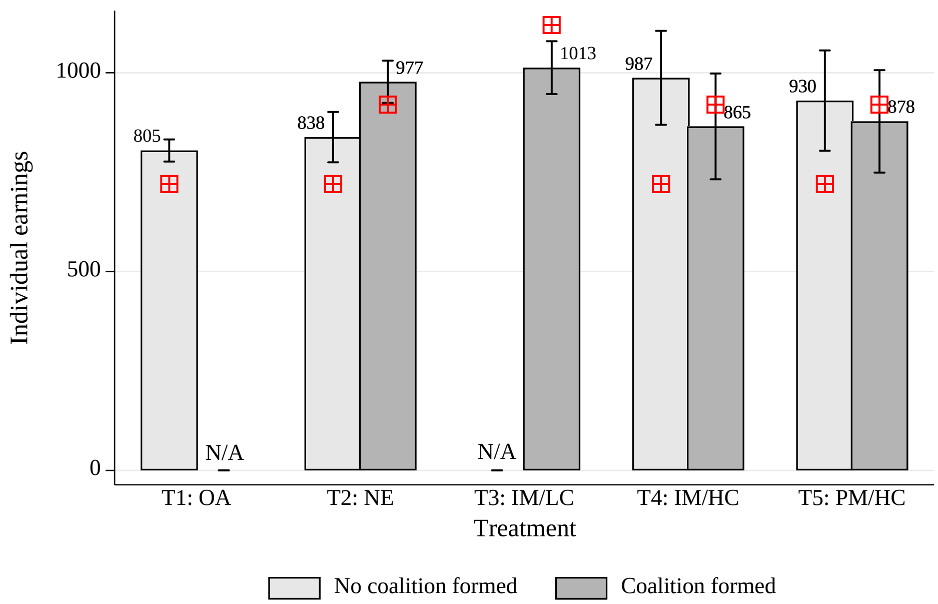

Figure 8. Average individual earnings (insiders + outsiders) per treatment: coalition formed vs. no coalition formed

Note: Estimated values from Model 1 in online supplement Table B-6. Red squares indicate equilibrium outcomes. Error bars indicate 95% confidence intervals. OA=Open Access treatment; NE=No Enforcement; IM/LC=Imperfect Monitoring/Low Cost; IM/HC=Imperfect Monitoring/High Cost; PM/HC=Perfect Monitoring/High Cost

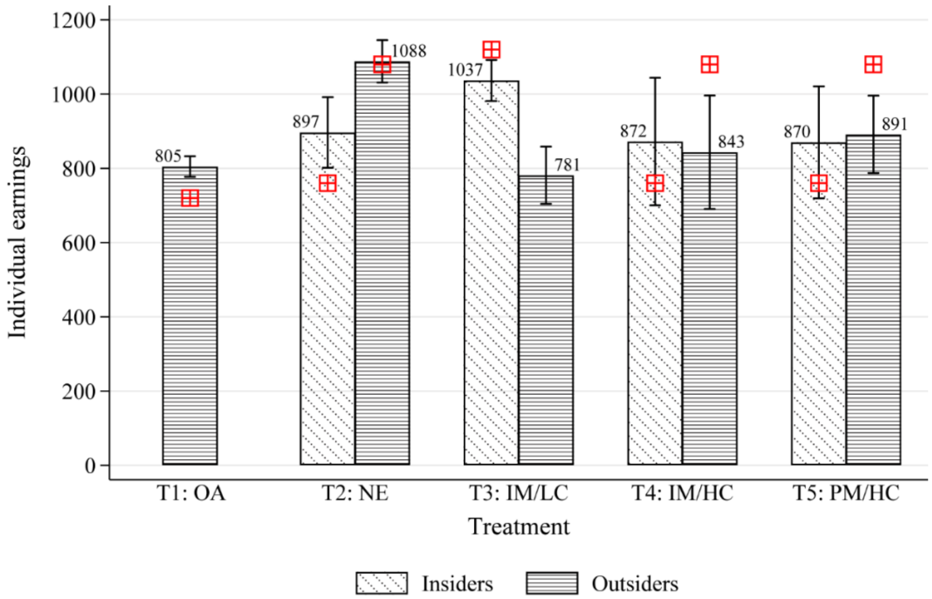

Figure 9. Average individual earnings per treatment, conditional on coalition formation.

Note: Estimated values from Model 1 in online supplement Table B-7. Red squares indicate equilibrium outcomes. Error bars indicate 95% confidence intervals. OA=Open Access treatment; NE=No Enforcement; IM/LC=Imperfect Monitoring/Low Cost; IM/HC=Imperfect Monitoring/High Cost; PM/HC=Perfect Monitoring/High Cost