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Common Pool Resource Appropriation under Costly Cooperation

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In addition to the usual fixed costs, we introduce variable costs in a community's effort to cooperate in extracting from a common pool resource. Using a standard supervision mechanism, these variable costs are shown to be an increasing function of individual members' incentives to default. The model explains why we frequently observe communities that all cooperate and have relatively similar resource endowments, and yet achieve very different levels of extraction.

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I. COOPERATION IN APPROPRIATING COMMON POOL RESOURCES

Because of the pervasiveness of common pool resources (CPR) and recurrent observation of their misuse, identifying the determinants of appropriation of these resources has generated considerable interest in many branches of the social sciences. These resources are characterized by joint access by a finite set of users and by rivalry in appropriation. When a community member decides individually on appropriation of a common pool resource, he generates negative externalities on others by reducing supply available to them. These externalities are, however, not taken into account in the individual's profit maximization calculus, leading to overuse of the resource.[1] This feature of CPR has been used to explain a variety of adverse environmental phenomena such as overgrazing and desertification, deforestation, soil erosion in watersheds, overdraft on underground aquifers, and overfishing. Observations in the field, however, show great variation in the quality of common pool resource management. While the literature tends to associate over-exploitation of resources with lack of cooperation and efficiency in resource management with cooperation (Ostrom [24]; Bromley [8]; Baland and Platteau [2]), our own observations suggest a whole range of intermediate levels of misuse, even among communities that seem to cooperate. The key questions raised by these observations are: How do some communities succeed in efficiently using their CPR? What explains what appear to be "intermediate" levels of cooperation?

[1] We do not discuss here the other aspect of a common pool resource, namely provision and the incentive to under-provide as individual actions create positive externalities on others. For provision problems in CPR, see Baland and Platteau [3], and de Janvry, McCarthy, and Sadoulet [11].

Turning to theory, three types of interpretations have been proposed to explain why communities may use their CPR efficiently. The first is that the decision on appropriation may correspond to non-cooperative games where the outcome of individual actions happens to be identical to a cooperative outcome. In the Assurance Game, for instance, both the cooperative and non-cooperative outcomes can be supported in equilibrium (Bardhan [4]). These particular payoff structures, however, characterize only a subset of rather specific situations of CPR appropriation.

The second interpretation calls on repeated games with trigger strategies where the Folk Theorem applies. The long-term perspective is appropriate for community affairs since there is usually considerable stability in membership. However, calling on trigger strategies that require either exclusion of access to the CPR or reversal to non-cooperation may have appeal in the oligopoly literature but are less useful in explaining community behavior: in most traditional communities, the threat of exclusion from the CPR is not credible, and the threat of reverting to non-cooperation when many members are involved would be too costly to too many others to be credible.

The third interpretation is that efficiency in resource use is obtained by cooperation (Ostrom [24]; McKean [21]; Bromley [8]; Berkes and Folke [6]). Cooperation, however, requires action by the community to define rules and to monitor and enforce them. As these actions entail costs, cooperation will be observed whenever the benefits of cooperation exceed the costs. The prospect for cooperation hence importantly depends on the factors that increase the expected gains from cooperation (Ostrom [24]; Wade [32]; Olson [23]; Bendor and Mookherjee [5]; Bardhan [4]). On the cost side, there is a large literature on how these costs vary and hence on how they affect the potential for cooperation (Sandler *et al.* [26] and references cited therein).

Much of the literature takes the community as given and considers costs of negotiation, supervision, and enforcement as fixed at the community level. Analyses focus on the factors that lower monitoring costs (Wade [32]; Hirschman [15]) or increase the ability to enforce rules (Hirschman [15]; Johnson and Libecap [16]; Besley and Coate [7]; Sethi and Somanathan [29]; Seabright [28]). Note that since these costs are fixed, they do not affect the optimum level of extraction, as cogently argued by a number of researchers (Seabright [28]). This theory can thus explain contrasts in extraction between non-cooperating and cooperating communities, but not the intermediate levels of extraction mentioned above.

Building on the importance of keeping groups small for efficiency purposes, a branch of the literature looks at the determination of the optimal number of firms when there are costs in containing membership. In Caputo and Lueck [9 and 10], communities must incur explicit costs for excluding potential exploiters. Assuming that costs of exclusion decrease with membership size (or equivalently increase with the number of potential exploiters to exclude), and that externalities and efficiency costs increase with membership size, the community settles for an optimal number of members. These results are akin to those found in the literature on the oligopolistic exploitation of a natural resource, although in this case the nature of the cost is quite different.[2] While these exclusion mechanisms are important in the area of commercial exploitation of resources, they are often not an option in traditional communities where extraction from the CPR is a right for all members of the community. It suggests, however, that whenever feasible, subcoalitions of members with control over a portion of the CPR might lead

[2] In the context of non-cooperative commercial exploiters that sell on a non-competitive market, the welfare cost of reducing membership to only one firm is the monopolistic behavior of the firm. Hence, the optimum lies between a small number of firms which may under-exploit the resources to capture the monopoly rent on the market, and a large number of firms which will over-exploit the resources because of the standard CPR externality problem (Mason and Polasky [18]; Mason *et al.* [19] and the references cited therein). These models also use non-cooperative games, while here we focus on understanding sub-optimal management of resources in cooperative games.

to better management (e.g., in the case of Mexican ejidos see Wilson and Thompson [33]). Nonetheless, once the size of the community has been decided, the level of resource extraction depends only on whether the members act cooperatively or non-cooperatively.

When exclusion from the community is not possible, communities only have the option of engaging in explicit supervision and punitive actions to ensure compliance with the cooperative agreement. A similar problem is found in the literature on the enforcement of pollution standards (Viscusi and Zeckhauser [31]; Harrington [13]; Harford and Harrington [12]). The individual cost to a firm of respecting a pollution standard increases with the severity of the standard. As each firm balances the expected punishment from non-complying with the cost of compliance, it chooses whether to comply or not. For a given enforcement mechanism (characterized by the probability that a non-complying firm would be caught and the penalty it would then have to pay), the regulator selects the optimal standard which leads to the lowest expected level of pollution. In equilibrium, the lowest pollution level is obtained with a mix of firms that abide by the standard and firms that prefer not to abide and risk paying the penalty.

Whereas in the pollution abatement literature, outcomes are "partial" in the sense that some fully cooperate whereas others fully do not cooperate, we are interested here in an outcome where all members agree to cooperate at a level below the costless cooperation outcome. In their game of provision of investment on a CPR, Caputo and Lueck [9 and 10] assume a reduced form for the enforcement mechanism, whereby the cost of enforcing any agreed upon aggregate level of investment is an increasing function of the level of investment. Adding to the price of the investment good, this enforcement cost reduces the optimal level of investment.

In this paper, we consider the management of common property pastures in the context of Mexican ejidos. In these communities, all members have access rights, and hence the communities do not have the option of excluding. We conceptualize the enforcement mechanism as in the pollution control literature, i.e., with explicit expenditures by the community and a resulting probability of catching cheating members. We, however, let the community choose both the expenditure on enforcement and the standard of extraction to maximize aggregate welfare. In addition, we do not allow for asymmetric treatment of herders, where the standard could be set at the individual level or where only a fraction of the community would abide by the cooperative agreement. This is because ejidos have a relatively strong governance structure based on deep-rooted egalitarian principles that do not easily allow for differential treatment of members.

We show that the optimal solution corresponds to enforcement expenditures that increase with the incentives of individual members to cheat, themselves an increasing function of the tightness of the standard, as assumed by Caputo and Lueck [9]. The resulting optimal extraction of the resource is an intermediate level between what would be obtained under a fixed cost cooperative regime and a non-cooperative regime. The intuition behind incorporating incentives to cheat into the determination of an optimal agreement was in fact presented by Stigler [30]. In that article, he assumes that oligopolists wish to collude, and that the successfulness of collusion will depend on the problems in policing a collective agreement. He notes that "if the enforcement is weak, however--if price-cutting is detected only slowly and incompletely--the conspiracy must recognize its weakness: it must set prices not much above the competitive level so the inducements to price-cutting are small" (Stigler [30], pg. 46). The model developed thereafter, however, focuses on determining how price-cutting might be determined, but does not return to how an optimal collusive price might be set, given incentives to cheat.

The model developed below explains the optimal agreed-upon level of extraction, and thus why we observe a wide range of quality of common pasture management, from extreme over-exploitation in communities where cooperation fails to relatively poorly managed resources where cooperation is obtained at high cots, and well-managed resources where cooperation is obtained at low cost. For any higher variable cost of enforcement, communities optimally choose to cooperate at a less stringent level of extraction.

In section II, we develop a model of costly cooperation when there are two identical community members; in section III, we extend the model to any number *m* of identical community members. Section IV concludes with a discussion of some policy implications of the model.

II. TWO-PLAYER MODEL OF COSTLY COOPERATION

The overall decision process on appropriation from a CPR is a two-stage game, where a cooperative agreement on the level of extraction and on the enforcement mechanism is chosen in the first stage, and members individually choose their effort levels in the second stage. Using backwards induction, the cooperative agreement in the first stage is chosen based on the incentives to deviate determined in the second-stage non-cooperative game. Costs are borne in the beginning of the period, whereas returns are realized at the end of the period. In the particular case of common property pasture that we develop in this paper, the terms of the cooperative agreement include the number of animals that each member can graze, the resources spent by the community on supervision and enforcement, and the penalty imposed on members caught cheating.

II.A. *The second-stage: non-cooperative choice of individual efforts*

Consider a two-person game over the number of animals (n_1, n_2) to graze on a common property pasture of given size H. We assume that the herders are homogenous, risk-neutral profit-maximizers, and that each herder has a constant marginal cost of stocking animals, $\bar{c}$. Productivity of forage for each individual is a decreasing function of the total number of animals stocked; thus, a crowding externality captures the negative effect of adding an additional head of cattle on the total weight for all animals stocked. However, each individual only internalizes that portion of the negative externality accruing to him. The profit from grazing is written:

$$\pi_i\ (n_1,\ n_2) = pn_i\left[a - \frac{b(n_1 + n_2)}{H}\right] - \bar{c}n_i; \quad i = 1,2, \tag{1}$$

where p is the price of livestock products, $n_i\left[a - \frac{b(n_1 + n_2)}{H}\right]$ is a commonly used cattle weight production function (see Hart *et al.* [14]), a is the pasture productivity coefficient, and b the pasture sensitivity to stocking coefficient.

Each of the two players contemplates two strategies: one is to cooperate and graze the number of animals agreed upon in a joint maximization, $n_i = n^*$, and the other to not cooperate and graze the number of animals consistent with individual maximization given the number of animals grazed by the other player:

$$n_i^0(n_j) = \arg\max \pi_i = \frac{a - \frac{\bar{c}}{p}}{2b} H - \frac{n_j}{2}; \quad i, j = 1,2; \quad i \neq j.$$

Let us call n^{00} the Nash non-cooperative solution when neither player cooperates:

$$n^{00} = \frac{a - \frac{\bar{c}}{p}}{3b} H.$$

II.B. *Incentives to cooperate or to defect and costs of enforcement*

Profits at the Nash non-cooperative solution are lower than those obtaining from joint-maximization. Hence, there are incentives for individuals to act collectively to secure rents from jointly owned resources. Incentives to cooperate are simply the additional revenues received when moving from the non-cooperative level to a cooperatively agreed upon level of extraction n:

$$I_i^C = \pi_i(n,\ n) - \pi_i\left(n^{00},\ n^{00}\right).$$

On the other hand, as explicitly captured in Prisoner's Dilemma games, there are incentives for a person not to cooperate. If he believes that all others will cooperate, then his best response is to not cooperate, and to add more animals. This is the incentive to cheat, which is equal to the difference between the profit of optimally cheating and the profit obtained by abiding by the agreement (given that the other person cooperates):

$$I_i^{Ch} = \pi_i\left(n_i^0(n),\ n\right) - \pi_i(n,n).$$

We can show that the incentive to cheat is always non-negative,

$$I_i^{Ch} = \frac{9}{4}\frac{bp}{H}\left(\frac{a-\frac{\bar{c}}{p}}{3b}H - n\right)^2 \geq 0.$$

Figure 1 illustrates these incentives and choices. Incentives to cooperate and to cheat are null at the non-cooperative level n^{00}. Thus, if the group "agrees" to cooperate at the level of the non-cooperative game outcome, then the gains from this agreement are zero and clearly incentives to cheat are also zero. As the group lowers its chosen cooperative level of extraction, gains from cooperating are increasing, though at a decreasing rate--a result that derives directly from the concave specification for the profit function. On the other hand, the incentives to cheat are increasing at an increasing rate.

Insert Figure 1

To capture the potential gains from cooperation, the group as a whole can set up an enforcement mechanism. We characterize this enforcement mechanism by its cost, which includes a fixed cost, Γ, and expenditures, C_i, spent on monitoring individual herders' behavior, and the penalty K imposed on the herders caught cheating. That enforcement of an agreement requires specific costs to supervise each individual, and not only an overall fixed cost, is justified in the case of common pastures when the number of animals grazing in large communal lands has to be monitored. The more effort the community puts into this monitoring, the higher is the probability that any cheating individual will be caught. If $\text{prob}(C_i)$ is the probability of being caught if cheating, then individual *i* will choose not to cheat if and only if:

$$\text{prob}(C_i)K - \left(1 - \text{prob}(C_i)\right)I_i^{Ch} > 0.$$

This defines the minimum expenditure level that the community has to incur to prevent *i* from cheating. It is an increasing function of the incentive to cheat I_i^{Ch}. To simplify the analytics of the problem, we choose a simple monitoring technique with:

$$\text{prob}(C_i) = \frac{\alpha C_i}{1 + \alpha C_i}.$$

The individual will thus abide by the cooperative level, n^*, if $C_i > I_i^{Ch} / \alpha K$, and act non-cooperatively, $n_i^0(n_j)$, if $C_i \leq I_i^{Ch} / \alpha K$.

II.C. *The first stage: overall welfare due to cooperation and cooperative equilibrium*

In the first stage, the members cooperatively choose the enforcement levels (resources Γ and C_i to expend in monitoring, and penalty K to impose to a member caught cheating) and the number of animals, n^*, that maximize the aggregate welfare of the group. The aggregate welfare is equal to the sum of all individual profits, net of the costs incurred for reaching an agreement and enforcing the rules and regulations. In addition, we only consider equilibria that can be sustained without explicit transfers between individuals, as such transfers are not observed in the contexts that we consider.[3] The cooperative solution n^* is enforceable without explicit transfer only if there is a positive profit gain from cooperation, $\pi_i(n^*, n^*) \geq \pi_i(n^{00}, n^{00})$, for each producer i. The group's problem is then:

$$\max_{n,K,C_i} \left\{ \sum_i \pi_i(n_i, n_j) - \sum_i C_i - \Gamma \right\}$$
$$\text{s.t.} \quad n_i = \begin{cases} n \text{ if } C_i > I_i^{Ch} / \alpha K, \\ n_i^0(n_j) \text{ otherwise,} \end{cases}$$
$$\pi_i(n^*, n^*) \geq \pi_i(n^{00},\ n^{00}),$$
$$i, j = 1, 2, \quad i \neq j.$$

The solution to this problem is to set the penalty K at a very high level and to induce cooperation with minimum cost and corresponding probability to catch a cheater. Yet, in real settings, a very high penalty cannot be extracted and hence the threat is not credible. The group then sets up the penalty at the maximum level, $K_{\max}$, that can be credibly extracted from individuals. Given the response function of individual members, the group retains only two

3 Disregarding the possibility of secondary transfers is classical in the literature on local cooperative behavior. See Ostrom and Gardner [25] and Seabright [27]. In any case, in the symmetric problem considered here, one can show that no solution would involve transfer.

possible values for C_i, either not to spend any resources and let the members cheat, or to spend the minimum amount $I_i^{Ch}/\alpha K_{\max}$ that ensures cooperation.[4] Correspondingly, the fixed cost Γ will only be spent if supervision is undertaken. Substituting these values in the problem above, the group's cooperative level for the number of animals is given by:

$$\begin{aligned} n^* &= \arg\max_n \left\{ W = \sum_i \pi_i(n,\ n) - \left(\gamma \sum_i I_i^{Ch} - \Gamma \right) 1\left(n \neq n^{00}\right) \right\} \\ \text{s.t.} \quad & \pi_i(n,\ n) \geq \pi_i\left(n^{00},\ n^{00}\right),\ i = 1,2, \end{aligned} \tag{2}$$

where $\gamma = 1/\alpha K_{\max}$ is the unit cost of enforcement, and $1\left(n \neq n^{00}\right)$ is the indicator function that takes value 1 if $n \neq n^{00}$ and 0 otherwise. This parameter is dimensionless; it measures the resources that have to be spent to prevent one player from cheating per unit of gain he would obtain by cheating. The costs parameters Γ and γ capture the group's ability to define rules, monitor the behavior of its members, and enforce rules. Consequently, they are a function of the socio-economic characteristics of the group (size of the group, observability of actions, social capital to retaliate, etc.) and the characteristics of the resource (well-defined boundaries, abundance, etc.) that were identified in Section I as factors determining the ability to cooperate.

Solution of the problem gives the enforceable cooperative solution:

$$\begin{aligned} n^* &= \frac{a - \frac{\bar{c}}{p}}{4b} H \left(\frac{1 + \frac{3}{2}\gamma}{1 + \frac{9}{8}\gamma} \right) = \frac{a - \frac{\bar{c}}{p}}{4b} H \eta(\gamma) && \text{if} \quad \Gamma \leq \Gamma_{\max}, \\ n^* &= n^{00} = \frac{a - \frac{\bar{c}}{p}}{3b} H && \text{if} \quad \Gamma > \Gamma_{\max}, \end{aligned} \tag{3}$$

[4] In equilibrium, resources will be spent to prevent cheating, so that no cheating should be observed. In this one period game, we assume that if cheating is observed during the period, the member will pay the penalty, and then play at the cooperative level.

where $\eta(\gamma) = \frac{1+\frac{3}{2}\gamma}{1+\frac{9}{8}\gamma} = \frac{n^*}{n_0^*}$ is overgrazing, defined as the costly cooperative optimum stocking relative to the optimal level of stocking n_0^* that would be obtained if cooperation had no variable cost, and

$$\Gamma_{\max} = \ p \ \frac{\left(a - \frac{\bar{c}}{p}\right)^2}{4b} H \frac{1}{3}\left(\frac{4}{3} - \eta\right)$$

is the maximum fixed cost that the community can bear.

We represent on Figure 1 the variable cost of cooperation, γI_i^{Ch} (the curve can lie below or above the incentive curve depending on the unit cost γ). The graph illustrates a very intuitive point: for agreements to cooperate at levels just slightly below the non-cooperative outcome, gains to this agreement are relatively large at the margin, whereas incentives to deviate from this point are relatively low at the margin. However, marginal gains to cooperation near the fixed-cost cooperation outcome are nearly flat (clearly they are zero at the fixed-cost cooperation outcome), whereas the marginal gains to deviate are at their highest over the relevant range (stocking rates between the non-cooperative and fixed-cost cooperative outcomes). Since welfare is equal to the difference between the gain in profits from cooperating and the variable cost of enforcing cooperation (eq. (2)), the optimal level of cooperation n^* is obtained when these marginal effects balance each other.

Expression (3) shows that the enforceable level of cooperation is independent of the level of fixed cost, and that it lies between the fixed-cost cooperative equilibrium (as calculated in standard cooperative models) and the non-cooperative equilibrium:

$$n_0^* = \frac{a - \frac{\bar{c}}{p}}{4b} H \leq n^* \leq n^{00} = \frac{a - \frac{\bar{c}}{p}}{3b} H.$$

This gives the range of variation for overgrazing: $1 \le \eta \le \frac{4}{3}$.

As the unit enforcement cost tends to 0 (which occurs when the community is more effective in enforcing the contract with higher penalty K or a more efficient monitoring technique, α), the community can tend to perfect cooperation. Conversely, with higher unit enforcement cost, the costly cooperation solution is much closer to the non-cooperative solution. Furthermore, since the maximum fixed cost, $\Gamma_{\max}$, is a decreasing function of the unit enforcement cost, γ, cooperation breaks down for lower values of the fixed cost as this cost increases.

If $\Gamma \le \Gamma_{\max}$, individual profit gains from cooperation are:

$$\pi_i\left(n^*, n^*\right) - \pi_i\left(n^{00}, n^{00}\right) = p\frac{\left(a - \frac{\bar{c}}{p}\right)^2}{8b} H\left(\eta - \frac{2}{3}\right)\left(\frac{4}{3} - \eta\right), \tag{4}$$

and the overall welfare is:

$$W = \ p \ \frac{\left(a - \frac{\bar{c}}{p}\right)^2}{4b} H \frac{1}{3}\left(\frac{4}{3} - \eta\right) - \Gamma. \tag{5}$$

III.D. *Comparative statics on the costly cooperation solution*

Expression (3) shows that overgrazing increases with the unit cost of enforcement and, for a very high unit enforcement cost, tends to the non-cooperative level. Both the non-cooperative number of livestock, n^{00}, and the costly cooperation level, n^*, are increasing functions of $\frac{a - \frac{\bar{c}}{p}}{b} H$. Individual profit gains from cooperation (4) and overall welfare gains (5) decrease with the unit costs of enforcement and, for very high unit enforcement costs, tend to zero. Profits, under both non-cooperation and cooperation, individual profit gains from cooperation (4), incentives to cheat, and overall welfare gains from cooperation (5) are all increasing with

$p\dfrac{\left(a-\frac{\bar{c}}{p}\right)^2}{b}H$. This shows that gains from cooperation are larger on pastures with better quality forage and that are less fragile, when product prices are higher, for more efficient livestock production, and when the magnitude of the resource over which cooperation occurs is greater. Yet, as seen in (3), the level of overgrazing η is unaffected by these variables and parameters.

III. MODEL WITH MORE THAN TWO MEMBERS

In this section, we expand the model to include any number of members, m. Membership, however, remains an exogenous variable. The choice variables thus remain the expenditures on enforcing the agreement and the stocking level. As all herders are assumed identical, we also restrict ourselves to symmetric solutions, and do not allow for the community to arbitrarily designate herders on which the contract will be enforced while others are allowed to cheat. Hence, only the two solutions of a costly cooperation agreement respected by all herders or non-cooperation are considered.

The incentive to cheat for any one member is the gain that could be made by cheating, given that all other members abide by the agreed cooperative level. Extending the formulation of the last section is quite straightforward. It leads to the following enforceable cooperative solution:

$$n^* = \frac{a-\frac{\bar{c}}{p}}{2mb}H\frac{1+\frac{m+1}{2}\gamma}{1+\frac{1}{m}\left(\frac{m+1}{2}\right)^2\gamma} = \frac{a-\frac{\bar{c}}{p}}{2mb}H\eta(\gamma) \quad \text{if} \quad \Gamma \le \Gamma_{\max},$$

$$n^* = n^{00} = \frac{a-\frac{\bar{c}}{p}}{(m+1)b}H \quad \text{if} \quad \Gamma > \Gamma_{\max},$$

where $\Gamma_{\max} = p\frac{\left(a-\frac{\bar{c}}{p}\right)^2}{b}H\frac{m-1}{4(m+1)}\left(\frac{2m}{m+1}-\eta\right)$ is the maximum fixed cost that the community can afford, and η is the level of overgrazing compared to the fixed-cost cooperation level. The total stocking level under cooperation is therefore:

$$N^* = mn^* = \frac{a-\frac{\bar{c}}{p}}{2b}H\frac{1+\frac{m+1}{2}\gamma}{1+\frac{1}{m}\left(\frac{m+1}{2}\right)^2\gamma} \quad .$$

As in the two players' case, n^* increases with the enforcement cost γ and always lies between the fixed-cost cooperation (obtained for $\gamma = 0$) and the non-cooperative levels, for any level of m. We note that $dn^*/dm < 0$, but that $dN^*/dm > 0$, as is the case under a non-cooperative game. As the number of herders increases, the total stocking level N^* approaches the non-cooperative stocking level (Figure 2).

The community welfare gain from entering into this cooperative agreement is the sum of the increase in profits for the individual herders net of the enforcement costs:

$$W^* = \sum_i \left(\pi_i^* - \pi_i^{00}\right) - \gamma \sum_i I_i^{Ch} - \Gamma = p\frac{\left(a-\frac{\bar{c}}{p}\right)^2}{b}H\frac{1-\frac{4m}{(m+1)^2}}{1+\frac{(m+1)^2}{4m}\gamma} - \Gamma ,$$

where π^* and π^{00} are profits at the cooperative and non-cooperative level of stocking. Figure 2 illustrates the evolution of the equilibrium as the number of members in the community increases. Welfare gains are represented gross of the fixed cost Γ. If there were no variable cost of enforcement ($\gamma = 0$), the welfare gain of cooperation would monotonically increase with the size of the community (curve 1 on Figure 2). This is because the externality imposed by non-cooperative behavior increases with the number of herders, and hence, as seen in the left-hand side of the figure, the non-cooperative stocking level N^{00} increases with the size of the community. Yet, when one includes the variable enforcement costs, the situation is different. At the given cooperative level, N_0^*, the benefit for one individual to cheat would increase with the remaining numbers of cooperating members. Hence, variable enforcement costs would increase. This induces an optimal relaxation of the standard, i.e., an increase in the cooperative level to N^* (left-hand side of graph). As the optimal stocking level increases, the profit gains from cooperation (curve 3) are not as high as when the lower level of stocking level N_0^* can be maintained. We thus see that the welfare gain from cooperation increases and then decreases as the size of the community increases (curve 4). This result indicates that, when a fixed cost Γ needs to be incurred to enforce cooperation, only communities not too small and not too large will choose the cooperative solution (between A and B). In small communities, the externalities of non-cooperation are not too high and it is not worthwhile incurring the fixed cost Γ of getting organized.[5] In very large communities, as the incentive for individual herders to cheat is very high, the cooperative level is set at a high level and the benefits from cooperation are not sufficient to justify incurring the fixed cost. Cooperation thus breaks down.

Insert Figure 2.

To summarize, the model developed above provides a framework for analyzing cooperative appropriation levels that are between the joint-maximization and the Nash non-cooperative solutions. The idea of partial success in cooperation has been analyzed by a number of authors, though most of the empirical evidence is anecdotal (Baland and Platteau [2]; Ostrom [24]; Oakerson [22]). Three studies which attempt to measure the extent of cooperation show varying

[5] One could argue that the fixed cost itself is small in small communities, and hence cooperation may still be profitable.

degrees of success. In Lopez [17] and Ahuja [1], the authors measure the degree of success communities have in managing the fertility of agricultural land in Côte d'Ivoire, where land in fallow produces a positive externality on land in individually cultivated plots by helping restore fertility. There is hence a social optimum in the allocation of community land between fallow and individual plots. Results from both studies suggest that communities cooperate, and that, in general, the degree of success in management lies between the outcomes associated with non-cooperative and with fixed-cost cooperative behavior.

In McCarthy *et al.* [20], we estimate stocking rates across nine Mexican ejido communities with common property pastures. In a first econometric model, communities are either fully cooperating or not; in a second, an index measuring the degree of cooperation is constructed. Results show that the index measuring the degree of cooperation has more explanatory power than a dichotomous cooperate/not cooperate specification, indicating that there are indeed different qualities of cooperation among these communities.

IV. CONCLUSION

We have developed a theory of cooperation that includes an explicit and costly mechanism of supervision and enforcement. Under fairly mild assumptions on this mechanism, we show that the optimal level of costs of monitoring and enforcing the agreed upon rules for appropriation of the CPR depends on the incentives that members have to defect, and on unit costs that capture the group's ability to monitor and enforce its rule. Introduction of these variable costs, as opposed to the fixed costs of enforcement usually considered in the literature, drastically modifies the outcome of the group-level maximization problem. As in the fixed-cost case, cooperation may break down if unit costs are too high. However, if an interior solution can be reached, the group optimally chooses a unique level of appropriation that lies somewhere between the non-cooperative level and the costless (or fixed-cost) cooperative level. The level of over-appropriation thus obtained is an increasing function of the unit costs of enforcement. This helps explain why cooperating communities with similar endowments and facing identical market conditions may choose different levels of resource appropriation. Among cooperating communities, the quality of cooperation will thus improve with community features and policy interventions that help reduce the variable costs of cooperation.

On the other hand, we also show that higher profitability (due to quality of the resource or the price of the commodity) leads to greater gains from cooperation, yet does not affect the degree of over-appropriation because it simultaneously increases the incentive to cheat. The model is highly stylized, but this is an interesting result that contradicts much of the current thinking on common-pool resource management. Thus, increasing market access and effective prices, and reducing production costs should not affect the degree of over-use, even though they increase the gains from cooperation, all else equal.

Furthermore, we show that the quality of cooperation and hence the benefits of cooperation at first increase and then decrease as the number of members increases. Hence, neither very large communities nor very small communities will find cooperation economically feasible, a regularity commonly observed in the empirical literature.

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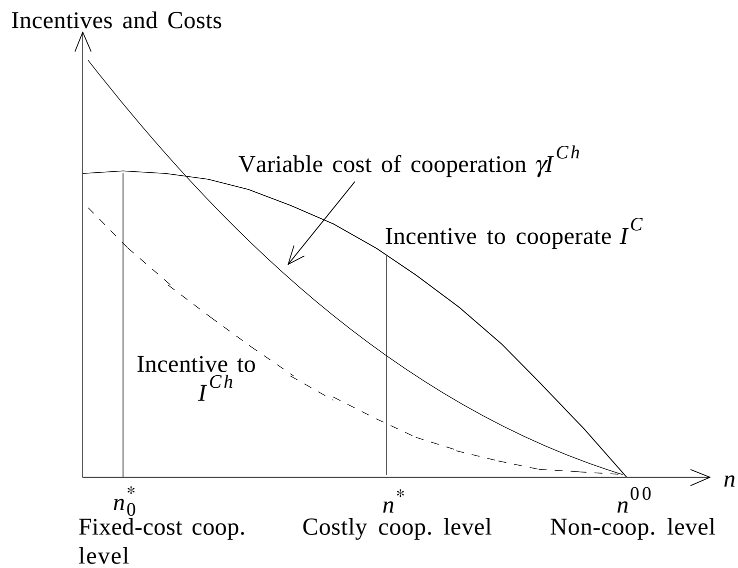

Figure 1. Incentives for cooperation and non-cooperation.

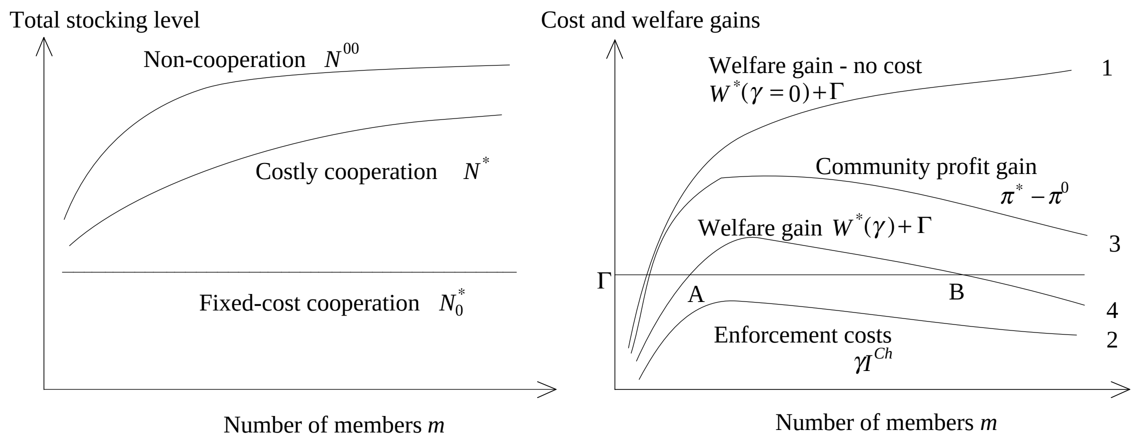

Figure 2. Cooperative solution as function of the number of members.