Common Pool Resource Appropriation under Costly Cooperation¹

by

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1. Cooperation in appropriating common pool resources

Because of their pervasiveness, and the recurrent observation of misuse, identifying the determinants of appropriation of common pool resources (CPR) has generated considerable interest in many fields of the social sciences. These resources are characterized by joint access by a finite set of users (outsiders can be excluded, but not individual community members) and by rivalry in appropriation (appropriation by one user reduces the supply available to others). When community members decide individually on the appropriation of a common pool resource, they create negative externalities on each others which they do not take into account in their private profit maximization calculus, leading to overuse of the resource.² This outcome of CPR has been used to explain a variety of phenomena such as overgrazing and desertification, deforestation, soil erosion in watersheds, overdraft on underground aquifers, and overfishing.

In recent years, however, a number of observers such as Ostrom (1992), Baland and Platteau (1996), and Bromley (1992) have refuted the hypothesis that all common-pool resources are inefficiently used. Turning to theory to explain this outcome, three types of interpretations have been proposed. One is that the decision on appropriation corresponds to a set of non-cooperative games where the outcome of individual actions is identical to a cooperative outcome. This includes game set ups such as the Chicken Game or the Assurance Game (Bardhan, 1993). These particular payoff structures, however, only characterize a subset of rather specific CPR situations. The second is to rely on repeated games with trigger strategies where the Folk Theorem applies. The long term perspective is appropriate for community affairs

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² 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 (1997), and de Janvry, McCarthy, and Sadoulet (1998). A model of costly cooperation in provision would be developed analogously to costly cooperation in appropriation.

since there is usually considerable stability in membership. However, in many community situations, exclusion of access to the CPR is not credible and the model is consequently also insufficient, The third and most appealing in thus to call on group-level cooperation resulting from the definition of rules, the monitoring of member behavior, and the enforcement of agreed upon rules. In the literature on cooperation, these community actions have been treated as fixed costs. If the benefits of cooperation exceed costs, cooperative behavior will be observed. Since these costs are fixed, they do not affect the optimum level of extraction cooperatively established. Hence, cooperation is a binary decision, and all cooperative levels should be identical for communities with identical primitives (objective function, technology, and fixed factors).

Much of the literature on cooperation has thus focused on the determinants of cooperation, identifying the factors that increase benefits and decrease costs. This has usually been done on the basis of case studies more than systematic empiricism. There is by now a long list of candidates among these determinants. They include factors that: (1) Increase the benefits from cooperation (a truly closed access resource with well defined boundaries and a well defined set of members (Ostrom, 1992; Wade, 1987); a smaller number of members over which to distribute the gains from cooperation (Olson, 1965; Bendor and Mookherjee, 1987); resource abundance that is neither too high or low (Bardhan, 1993)). (2) Lower monitoring costs (smaller groups, greater proximity and homogeneity (Wade, 1987), longer together (Hirschman, 1970)). And (3) increase the ability to enforce rules (leadership, high cost of exit option (Hirschman, 1970), homogeneity and perception of fairness in distribution of the gains from cooperation (Johnson and Libecap, 1982), interlinkages (social capital) among community members (Besley and Coate, 1995), credibility of threats and commitment of sanctions, availability of conflict resolution mechanisms (Ostrom, 1992), metapunishment mechanisms, shared social norms (Sethi and Somanathan, 1996) and trust capital (Seabright, 1994)).

Observations we made in field work, however, repeatedly suggested another interpretation of the determinants of cooperation. Identical communities in terms of primitives cooperate with differential outcomes in terms of levels of resource appropriation. Hence, while cooperation is indeed dichotomous (cooperate or not), there are different "qualities" of cooperation, with levels of resource appropriation

observed somewhere in the interval between fixed cost cooperation and non-cooperation. This suggests that variable costs of cooperation enter into the determination of the social optimum. How these costs are defined and how they bear on the optimum level of CPR use is the objective of this paper. Formalizing a model of cooperative behavior under costly cooperation opens a vast field of reinterpretation of observed cooperative behavior.³ It allows to specify when cooperative behavior will be observed, the optimum level of resource appropriation given the gains and costs of cooperating, and how this optimum level is affected by changes in a number of exogenous variables and parameters that characterize the primitives of the problem, prices, and the degree of heterogeneity in the community.

We choose the most general formulation of the problem in assuming that the costs of cooperating are function of the individual incentives to defect from the agreed upon rules and that these incentives are derived from the solution of the non-cooperative game. There are two types of incentives for an individual not to cooperate that follow two contrasted visions of human nature. According to the first vision, if an individual believes that all others will cooperate, then his best response is to not cooperate. This is the incentive to cheat, and it is equal to the difference between the profit obtained from abiding by the agreement (given that the others cooperate) and the profit of optimally cheating. It is motivated by the pursuit of "self-interest with guile" (Williamson, 1982) that typifies the postulate of methodological individualism in the new institutional economics (Bardhan, 1989), and is also the standard behavioral postulate in the theory of oligopolistic behavior. The second type of incentives to default starts from a vision that human beings are fundamentally driven to cooperate, possibly because they have internalized social norms through communal living and through experiencing rewards and punishments in a way that makes them behave beyond self-interest (Dasgupta, Chapter 8, 1993). However, these willing cooperators do not want to be duped into cooperating when others do not. As explained by Sugden, individuals' cooperation in using CPR is conditional on their expectation that others will cooperate as well (Sugden, 1995; White and Runge, 1994). In this case, the incentive to default is avoiding the loss created by the difference between the profits when duped into cooperating while the others default and not cooperating at all. Incentives to deviate from the cooperative agreement are, in general, a combination of both types of

³ In what follows, we refer to costly cooperation as a situation where cooperation entails variable costs in addition to the traditional fixed costs.

incentives, weighted by the unit costs of counteracting each type of incentive to default. Enforcement costs \

can be expected to increase with these incentives to default: The larger the incentives, the more creative will a community member be in trying to cheat and conceal its acts, and hence the more difficult it may be to detect cheating and enforce rules.

The role of heterogeneity on cooperation has been extensively debated in the literature. Heterogeneity has been associated both with poor cooperative performance (Ostrom, 1992; Kanbur, 1992) and with successful performance (Olson, 1965; Baland and Platteau, 1997). As noted by Baland and Platteau, there are many types of heterogeneity and they bear differentially on cooperation. We explore here two types of heterogeneity: differentials in production costs and differential constraints on capacity to appropriate. We show that, under costly cooperation, heterogeneity restricts the ability to find an acceptable cooperative solution, and that inequality in capacity reduces the optimal over appropriation in the cooperative solution.

In the analysis that follows, we consider the CPR to be community pasture land where community members choose the optimal number of animals to stock. This allows us to use a linear-quadratic specification of the production function that has been widely used in studies of livestock weight gain (Hart et al., 1989).

In section 2, we develop the model of costly cooperation when community members are identical. We then consider in section 3 the case where heterogeneity comes from differential production costs across members. In section 4 heterogeneity results from differential constraints on capacity to stock animals. Section concludes with a discussion of some policy implications of the model.

2. Basic symmetric model of costly cooperation

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, c . Productivity of forage for each individual is a decreasing function of the total number of animals stocked; thus, a crowding out externality captures the negative effect of adding an additional head of cattle on total weight gain for all animals

stocked. However, each individual only internalizes that portion of the negative externality accruing to him. The profit from grazing is therefore written:

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

where p is the price of livestock products and $n_i \left[a - \frac{b(n_i + n_j)}{H} \right]$ is a commonly used cattle weight gain function (see Hart et al., 1989) where 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:

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

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

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

There are incentives for individuals to act collectively to secure rents from jointly owned resources, but, in reality, there are also costs of securing these rents, i.e., of ensuring that the cooperative solution will be reached. We assume that the equilibrium cooperation level can be enforced if the group undertakes such costly supervision and punishment measures. These enforcement costs are hypothesized to be a function of private incentives for members to deviate from any agreed upon level.

Incentive to defect from cooperation and cost of enforcement

Incentives to cooperate are simply the additional revenues received when moving from the non-cooperative level to a cooperatively agreed upon level of extraction:

$$I_i^C = \pi_i(n^*, n^*) - \pi_i(n^{oo}, n^{oo})$$

On the other hand, as explicitly captured in Prisoner's Dilemma games, there are two types of 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 to the agreement (given that the other person cooperates):

$$I_i^{Ch} = \pi_i(n_i^o(n^*), n^*) - \pi_i(n^*, n^*).$$

The second type of incentive to consider is associated with avoiding losses that would be born if one were to be duped, i.e., of cooperating while the other person cheats. The incentive to not be duped is the potential loss in profit from cooperating when individual j himself cheats (i.e., when j plays its best response to whatever i decides to do, which is $n_j^o(n^*)$ if i cooperates and n^{oo} if i does not cooperate):

$$I_i^{ND} = \pi_i(n^{oo}, n^{oo}) - \pi_i(n^*, n_j^o(n^*)).$$

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

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

while the incentive to not be duped

$$I_i^{ND} = \frac{1}{2} \frac{b}{H} \left(n^* - \frac{a - \bar{c}/p}{3b} H \right) \left(n^* - \frac{2(a - \bar{c}/p)}{3b} H \right)$$

is non-negative when the cooperative level is lower than the non-cooperative equilibrium, $n^*(n^o) \leq n^{oo}$, only values for which the specification is meaningful.

We assume that the enforcement costs necessary to ensure cooperation increase with the incentives to defect as follows:

$$\gamma^{Ch} \sum_i I_i^{Ch} + \gamma^{ND} \sum_i I_i^{ND}, \quad i = 1, 2,$$

where γ^{Ch} and γ^{ND} are unit costs of enforcement. These unit costs capture the group's ability to define rules, monitor the behavior of its members, and enforce rules. They are consequently function of the socioeconomic characteristics of the group (size of the group, observability of actions, social capital to retaliate, etc.) and the characteristics of the resources (well defined boundaries, abundance, etc.) that were identified in section 1 as factors determining the ability to cooperate.

Overall welfare due to cooperation and cooperative equilibrium

The group's cooperative behavior results from the maximization of aggregate profit gain from cooperation, net of the costs incurred for making agreements and enforcing rules and regulations.

Cooperation is chosen over the alternative non-cooperative behavior only if it leads to a positive gain. 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.⁴ The cooperative solution is enforceable without explicit transfer only if there is a positive profit gain from cooperation, $\pi_i(n^*, n^*) \geq \pi_i(n^{\circ\circ}, n^{\circ\circ})$, for each producer i . Hence the group's cooperative behavior is given by:

$$\begin{aligned} \max_n W &= \sum_i [\pi_i(n^*, n^*) - \pi_i(n^{\circ\circ}, n^{\circ\circ})] - \gamma^{Ch} \sum_i I_i^{Ch} - \gamma^{ND} \sum_i I_i^{ND} \\ \text{s.t. } &\pi_i(n^*, n^*) \geq \pi_i(n^{\circ\circ}, n^{\circ\circ}) \quad i = 1, 2 \quad i \neq j \\ &W \geq 0 \end{aligned} \quad (2)$$

Solution of the problem gives the enforceable cooperative solution:

$$\begin{aligned} n^* &= \frac{a - \bar{c}/p}{4b} H \left(\frac{1 + \frac{3}{2}\gamma^{Ch} + \frac{1}{2}\gamma^{ND}}{1 + \frac{9}{8}\gamma^{Ch} + \frac{1}{4}\gamma^{ND}} \right) = \frac{a - \bar{c}/p}{4b} H\eta \quad \text{if } \gamma^{ND} \leq 2 \\ n^* &= n^{\circ\circ} = \frac{a - \bar{c}/p}{3b} H \quad \text{if } \gamma^{ND} > 2 \end{aligned} \quad (3)$$

where $\eta = n^*/n_o^*$ is overgrazing, defined as the costly cooperative optimum stocking rate relative to the optimal level of stocking n_o^* that would be obtained if cooperation had no variable cost. This expression shows that the enforceable level of cooperation lies between the costless cooperative equilibrium (as calculated in standard cooperative models) and the non-cooperative equilibrium:

$$\begin{aligned} n_o^* &= \frac{a - \bar{c}/p}{4b} H \leq n^* \leq n^{\circ\circ} = \frac{a - \bar{c}/p}{3b} H \quad \text{for } \gamma^{Ch} \geq 0 \quad \text{and} \quad 0 \leq \gamma^{ND} \leq 2, \\ \eta &= 1 \text{ if } n^* = n_o^*, \quad \eta = 4/3 \text{ if } n^* = n^{\circ\circ}. \end{aligned}$$

Individual profit gains from cooperation are:

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

and the overall welfare is:

$$W = \frac{(a - \bar{c}/p)^2}{b} H \frac{1}{4} \left(\frac{4}{3} - \eta \right) \left(1 - \frac{1}{6} \gamma^{ND} \right). \quad (5)$$

⁴ Disregarding the possibility of secondary transfers is classical in the literature on local cooperative behavior. See Ostrom and Gardner (1993) and Seabright (1993).

Figure 1. Incentives to cooperate and not-cooperate

Figure 1 illustrates these incentives and choices. Incentives to cooperate, cheat and not be duped are all zero at the non-cooperative level n^{∞} . 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 and not be duped are also zero. As the group moves towards the costless cooperation outcome n^* , 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, both the incentives to cheat and the incentives not to be duped are increasing at an increasing rate. 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 costless cooperation outcome are nearly flat (clearly they are zero at the costless cooperation outcome), whereas the marginal gains to deviate are at their highest over the relevant range (stocking rates between the non-cooperative and costless cooperative outcomes). The optimal level of cooperation n^* is obtained when these marginal effects balance each others.

Comparative static on the cooperative solution

Expression (3) shows that overgrazing increases with the unit costs of enforcement and, for very high unit enforcement costs, tends to the non-cooperative level. Both the non-cooperative number of

livestock n^{∞} and the cooperative level n^* are increasing functions of $\frac{a-\bar{c}/p}{b}H$. 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 non-cooperation and under cooperation, individual profit gains from cooperation (4), incentives to defect, and overall welfare gain from cooperation (5) are all increasing with $\frac{(a-\bar{c}/p)^2}{b}H$. This shows that gains from cooperation are larger on better pastures, when product prices are higher, for more efficient livestock production, and when the magnitude of the resource over which cooperation occurs is greater.

3. Heterogeneity in production costs

As with other factors hypothesized to affect the successfulness of common-pool resource regulation, greater “heterogeneity” has been associated with both poor management performance (Ostrom, 1992) and eventually successful management (Olson, 1992; Baland and Platteau, 1997). As noted in Baland and Platteau however, heterogeneity can come in a wide variety of forms: heterogeneity in interests (multiple uses), heterogeneity in socio-cultural norms, heterogeneity in endowments, to name but a few. In the next two sections, we will be concerned with heterogeneity in either the constant marginal costs facing each producer, or in a constraint on stocking levels that is binding for only one producer.

Suppose now that the two herders have differential production costs, with herder i more efficient than herder j , i.e., $c_j > c_i$. Heterogeneity is defined by $\delta = \frac{c_j - c_i}{2}$, and the average production cost is $\bar{c} = \frac{c_i + c_j}{2}$.

The non-cooperative reaction function of household i is

$$n_i^c(n_j) = \frac{a - c_i/p}{2b}H - \frac{n_j}{2}$$

and the non-cooperative equilibrium is:

$$n_i^{\infty} = \frac{a - \bar{c}/p}{3b}H + \frac{(\bar{c} - c_i)/p}{b}H.$$

Hence, the total number of animals under non-cooperation is:

$$N^{\circ\circ} = \frac{2(a - \bar{c}/p)}{3b} H,$$

and profits are:

$$\pi_i(n_i^{\circ\circ}, n_j^{\circ\circ}) = \frac{b}{H} (n_i^{\circ\circ})^2.$$

In this case, we see that the total number of animals $N^{\circ\circ}$ is the same as when herders are homogenous in production costs since this number is a function of average cost only. The low cost producer clearly stocks more than the high cost producer, and his profit is correspondingly greater. The difference in stocking rates between the two producers is a function of the difference in costs and of the parameter b which captures the magnitude of the negative externality imposed by use. The greater the magnitude of this externality, the lower is the difference in stocking rates between the two producers.

Cooperative solution

We only consider the symmetric solution in which both producers have equal grazing rights. Assume that j is a high cost producer compared to i , i.e., $c_j > c_i$. We can show that the profit gain from cooperation is larger for the high cost producer,

$$\pi_j(n^*, n^*) - \pi_j^{\circ\circ} > \pi_i(n^*, n^*) - \pi_i^{\circ\circ},$$

if and only if $n^* < \frac{2}{3} \frac{a - \bar{c}/p}{b} H$, which we will see later is always true. The incentive compatibility constraint to accept cooperation,

$$\pi_j(n^*, n^*) - \pi_i(n_i^{\circ\circ}, n_j^{\circ\circ}) = n^*(a - c_i - 2bn^*) - bn_i^{\circ\circ 2} \geq 0,$$

only needs be imposed for the low cost producer i . This is because the low cost producer had more animals under non-cooperation and hence will have to reduce his herd size by more than the high cost producer under cooperation. This constraint can be written:

$$\begin{aligned} \frac{a - \bar{c}/p}{4b} H \eta_{\min} &< n^* < \frac{a - \bar{c}/p}{4b} H \eta_{\max}, \\ \text{with } \eta_{\min} &= 1 + \frac{\delta}{a - \bar{c}} - \sqrt{\left(1 + \frac{\delta}{a - \bar{c}}\right)^2 - \frac{8}{9} \left(1 + 3 \frac{\delta}{a - \bar{c}}\right)^2} \\ \text{and } \eta_{\max} &= 1 + \frac{\delta}{a - \bar{c}} + \sqrt{\left(1 + \frac{\delta}{a - \bar{c}}\right)^2 - \frac{8}{9} \left(1 + 3 \frac{\delta}{a - \bar{c}}\right)^2}, \end{aligned}$$

which requires that the term under the square root be positive, i.e., that heterogeneity

$$\delta \leq \delta_{\max} = \frac{3-2\sqrt{2}}{2\sqrt{2}-1} \frac{a-\bar{c}/p}{3}.$$

This means that the low cost producer will not find profitable a cooperative level that forces him to reduce his herd size by too much, or allows the high cost producer to decrease his herd size by too little. This will happen if there was large heterogeneity in production costs and hence in non-cooperative herd sizes. The welfare gain from cooperation W is a quadratic function in n^* , which is positive for values between its two roots, $n_a < n^* < n_b$, where n_b is a decreasing function of inequality and of the unit enforcement costs.

The optimal cooperative solution under the incentive compatibility constraint

$$\text{Max}_{n^*} W \quad \text{s.t.} \quad \pi_i(n^*, n^*) \geq \pi_i(n_i^{\circ\circ}, n_j^{\circ\circ}); i, j = 1, 2; \text{ and } W \geq 0 \text{ gives}$$

$$\text{if } \eta_{\min} < \eta < \eta_{\max}, \text{ then } n^* = \frac{a-\bar{c}/p}{4b} H \frac{1 + \frac{3}{2}\gamma^{Ch} + \frac{1}{2}\gamma^{ND}}{1 + \frac{9}{8}\gamma^{Ch} + \frac{1}{4}\gamma^{ND}} = \frac{a-\bar{c}/p}{4b} H\eta, \quad \eta \geq 1,$$

which is independent of the level of heterogeneity, i.e., the same solution than under homogeneity.

$$\text{If } \eta < \eta_{\min}, \text{ then } n^* = \frac{a-\bar{c}/p}{4b} H\eta_{\min}$$

$$\text{if } \eta > \eta_{\max}, \text{ and } \frac{a-\bar{c}/p}{4b} H\eta_{\max} < n_b \text{ then } n^* = \frac{a-\bar{c}/p}{4b} H\eta_{\max}$$

$$\text{if } \eta > \eta_{\max}, \text{ and } \frac{a-\bar{c}/p}{4b} H\eta_{\max} > n_b \text{ then there is no cooperative solution that leads to a positive}$$

welfare.

These results are summarized in Figure 2. At given heterogeneity δ , if unit enforcement costs are not too high ($\eta_{\min} < \eta < \eta_{\max}$), then the cooperative solution is enforceable and brings positive welfare (between A and B). As the enforcement costs increase, the cooperative number of animal increases (and profits decrease) to reach the limit where the low cost producer enjoys no gain in profit from cooperation (at B, where $\eta = \eta_{\max}$), but the overall welfare is still positive. As enforcement unit costs still increase, this cooperative limit does not even lead to positive welfare, and thus breaks down to lead to non-cooperative behavior. (This is represented on Figure 3 at C, although W is directly function of the unit costs γ , and not a function of the transformation η .) At high levels of heterogeneity, the most efficient producer would

loose in a cooperative equilibrium with a number of animals below $n^* = \frac{a - \bar{c}/p}{4b} H\eta_{\min}$, which becomes the minimum acceptable level. Finally, with heterogeneity too high, $\delta > \delta_{\max}$, no cooperation is possible.

Note: The wiggled line $W = 0$ indicates that the welfare gain from cooperation W is not function of η but of the two unit costs γ .

Figure 2. Cooperative solution with heterogeneity in production costs

We thus find that heterogeneity influences the limit to cooperation, but not the level of cooperation for the interior solution. This is to say that, when comparing a community whose members are heterogeneous with another community whose members are homogeneous in terms of marginal costs but have the same average cost, total stocking rates will be the same in the two communities. Note that similar results obtain for the non-cooperative game. Therefore, the degree of overstocking and the extent of losses to producers in non-cooperation is the same whether members are homogenous or heterogenous – as long as an interior solution can be reached for the group-cooperation problem.

An interior solution of the group maximization problem may not be reached when rights are allocated equally among members if 1) the difference in production costs becomes too large, for given unit costs of cooperation, or 2) unit costs of cooperation are too high. Again, the high-cost member will always gain from enforcement of lower stocking levels than those that obtain at the non-cooperative equilibrium. However, the low-cost producer will always gain by less, and may even lose.

It is interesting to combine this result with the results from section 2, where producers are homogenous, to analyze the impact on cooperation of an increase in productivity in cattle raising (a decrease in costs). As mentioned in the introduction, there is some confusion as to whether changes that make exploitation of a common property resource more profitable will be beneficial or harmful to a community's ability to cooperate; though, much of the case study literature and anecdotal evidence seem to favor the hypothesis that improved profitability will have negative consequences for group cooperation. Consider how the following hypothetical differential evolution of cost structures may affect the ability of a community to cooperate over time. The community starts with relatively homogenous members (in terms of marginal costs) and assume that a group cooperation solution has been reached. Over time, only a certain fraction of the producers becomes more efficient. In our analysis, when producers are homogenous, higher product prices, higher pasture productivity, and lower costs all lead to greater welfare gains from cooperation. However, if only a fraction of the members is becoming more efficient and the gap in marginal costs widens, it becomes more likely that no group cooperation solution will remain feasible. Cooperation may in fact break down, resulting in over appropriation of the resource and lower profits for the group as a whole.

4. Heterogeneity in stocking capacity

Assume that herder 1 is constrained in the number of animals he can acquire, $n_1 < \bar{n}_1$, and that the constraint is effective in the non-cooperative equilibrium, i.e., $\bar{n}_1 < n^{oo} = \frac{a - \bar{c}/p}{3b}H$, but not in the cooperative equilibrium (to be determined), i.e., $\bar{n}_1 > n^*$. If it was constrained under the cooperative equilibrium, $\bar{n}_1 < n^*$, then herder 2 would always prefer the non-cooperative solution. In this section, herders have equal marginal production costs.

In the non cooperative equilibrium:

$$n_1^o = \bar{n}_1, \text{ and } n_2^o = \frac{a - \bar{c}/p}{2b}H - \frac{\bar{n}_1}{2}.$$

This shows that herder 2 raises more animals than if herder 1 was not constrained, but overall there are still fewer animals than in the unconstrained case:

$$N_{cons}^{\circ\circ} = \frac{a - \bar{c}/p}{2b} H + \frac{\bar{n}_1}{2} < N^{\circ\circ} = 2 \frac{a - \bar{c}/p}{3b} H.$$

As the constraint on the number of animals herder 1 can acquire becomes tighter, i.e., $\bar{n}_1$ decreases from the maximum $n^{\circ\circ}$ he would wish to acquire to zero, the non-cooperative solution $N_{cons}^{\circ\circ}$ tends toward the most efficient solution. At the limit, if $\bar{n}_1 = 0$, producer 2 is left alone on the common pasture land and chooses to use the pasture optimally.

Derivation of the incentives to defect from cooperation relative to the constrained level $\bar{n}_1$ shows that a tighter $\bar{n}_1$ reduces the potential benefits of defaulting for herder 1 (both the incentives to cheat and not be duped), and increases the incentive to not be duped for herder 2. The impact on the overall enforcement cost is thus undetermined.

As previously, we only consider cooperative solutions that give equal grazing rights to the two herders. Regarding the incentive and positive welfare constraints,

$$\pi_i(n^*, n^*) \geq \pi_i(n_i^{\circ\circ}, n_j^{\circ\circ}); \quad i = 1, 2; \quad i \neq j; \quad \text{and} \quad W \geq 0,$$

we can show that:

a) The constrained herder 1 always gains from cooperation. This is because:

$$\pi_1(n^*, n^*) = pn^* \left(a - \bar{c}/p - \frac{2bn^*}{H} \right) > p\bar{n}_1 \left(a - \bar{c}/p - \frac{2b\bar{n}_1}{H} \right) > p\frac{1}{2}\bar{n}_1 \left(a - \bar{c}/p - \frac{b\bar{n}_1}{H} \right) = \pi_1(\bar{n}_1, n_2^*(\bar{n}_1)).$$

Hence the incentive constraint need only be imposed for the unconstrained herder 2.

b) The profit gain from cooperation for herder 2 is a quadratic expression in n^* and $\bar{n}_1$:

$$\Delta\pi_2 = \frac{bp}{H} \left[-2n^{*2} + \frac{a - \bar{c}/p}{b} Hn^* - \frac{1}{4} \left(\frac{a - \bar{c}/p}{b} H - \bar{n}_1 \right)^2 \right].$$

This expression is always negative for values of the constraints $\bar{n}_1 < \bar{n}_{1\min} = \left(1 - \frac{\sqrt{2}}{2} \right) \frac{a - \bar{c}/p}{b} H$. This says

that if herder 1 faces a very tight limit on his herd size, then herder 2 will always have higher profit by not cooperating. For values of the constraint above this limit, the profit gain is positive for cooperative values between the two roots, i.e., neither too small nor too large. This is illustrated in Figure 3, where the curve $\Delta\pi_2(n^*)$ is represented for increasing level of the constraint $\bar{n}_1$.

c) The welfare is also a quadratic expression in n^* and $\bar{n}_1$:

$$W = -n^{*2} \left[4 + \frac{17}{4} \gamma^{Ch} + \frac{3}{2} \gamma^{ND} \right] + n^{*2} \left[\left(2 + \frac{5}{2} \gamma^{Ch} + \frac{3}{2} \gamma^{ND} \right) \frac{a - \bar{c}/p}{b} H + \bar{n}_1 (\gamma^{Ch} - \gamma^{ND}) \right] - \frac{1}{4} (1 + \gamma^{ND}) \left[\left(\frac{a - \bar{c}/p}{b} H \right)^2 - \bar{n}_1^2 \right] - \gamma^{Ch} \left(\frac{1}{4} \left(\frac{a - \bar{c}/p}{b} H \right)^2 + \left(\frac{a - \bar{c}/p}{b} H \right) \bar{n}_1 - \bar{n}_1^2 \right).$$

It takes positive values for cooperative values n^* between its two roots. Figure 3 shows the welfare as a function of n^* for increasing values of the constraint $\bar{n}_1$. Note that the profit gain $\Delta\pi_2$ is independent of the enforcement costs, while the welfare W is a decreasing function of the enforcement costs.

Figure 3 Welfare and unconstrained herder's profit as the stocking constraint changes

Summarizing these conditions gives the following solution for the constrained optimization of welfare:

a) At very low level of $\bar{n}_1 < \bar{n}_{1\min}$, herder 2 will always prefer to default. This is case $\bar{n}_1^1$ in Figure 3, with negative profit gain $\Delta\pi_2^1$ for herder 2 at all level of n^* .

b) At higher level, $\bar{n}_{1\min} < \bar{n}_1 < \bar{n}_0$, profits for herder 1 will only be positive for low level of overgrazing. But then, enforcement costs are so high as to make overall welfare negative. Hence, no solution can both ensure the unconstrained herder's incentive constraint and lead to a positive welfare. This is illustrated for $\bar{n}_1^2$ in Figure 3. Let $\bar{n}_0$ be the lowest value for which $\Delta\pi_2$ and W have a common root n^* .

c) If $\bar{n}_1 > \bar{n}_0$, the constrained cooperative solution is the maximum value acceptable by herder 2,

$$n^* = \frac{a - \bar{c}/p}{4b} H + \frac{1}{4} \sqrt{\left(\frac{a - \bar{c}/p}{b} H\right)^2 - 2\left(\frac{a - \bar{c}/p}{b} H - \bar{n}_1\right)^2}.$$

This correspond to case $\bar{n}_1^3$ of Figure 3 with the cooperative equilibrium at n^{*3} .

d) As $\bar{n}_1$ increases further, profit gain is no longer constraining on herder 2 and the level of cooperation is only limited by the cost of enforcement. The optimal solution correspond to the maximum welfare (case $\bar{n}_1^4$ in Figure 3):

$$n_{cons.}^* = \frac{a - \bar{c}/p}{b} H \left[\frac{2 + \frac{5}{2}\gamma^{Ch} + \frac{3}{2}\gamma^{ND}}{8 + \frac{17}{2}\gamma^{ND} + 3\gamma^{ND}} \right] + \bar{n}_1 \frac{\gamma^{Ch} - \gamma^{ND}}{8 + \frac{17}{2}\gamma^{ND} + 3\gamma^{ND}}.$$

This expression shows that, in absence of enforcement costs, the constraint does not affect the solution. This is because the constraint only affects the incentives to deviate, and not the profit under cooperation. Second, in the particular instance where the unit enforcement costs are equal, the decrease in the incentives to deviate for herder 1 and the increase in the incentive to not be duped for herder 2 exactly compensate each other. In that case, the cooperative level is independent of the constraint. In the more general case where $\gamma^{Ch} > \gamma^{ND}$, a tighter constraint (lower $\bar{n}_1$) allows the reduction of stocking rate in the cooperative solution.

This path of constrained solution is represented in the $(n^*, \bar{n}_1)$ space in Figure 4, where the curve of zero profit gain for herder 2 and zero welfare gain from cooperation are reported (at $\bar{n}_a$, profit gain for herder 2 is positive for cooperative values n^* between points A and B, and aggregate welfare is positive between C and D). We see that below $\bar{n}_0$, there is no value of n^* that satisfies both constraints of positive profit gain and positive welfare. Above $\bar{n}_0$, n^* is first determined by the unconstrained herder' profit constraint, and then takes the interior solution that maximize aggregate welfare.

Figure 4. Cooperative solution with one herder with stocking constraint

5. Conclusion

We have developed a theory of cooperation in which we assume that the costs of monitoring the behavior of members and enforcing the agreed upon rules for appropriation of the CPR depend on the incentives that members have to defect (I_i^{Ch} , I_i^{ND}) and on unit costs that capture the group's ability to monitor and enforce its rules (γ^{Ch} , γ^{ND}). These incentives are of two types: the incentive to cheat when others are cooperating, and the fear of being duped in cooperating while the other members cheat.

Introduction of these variable costs, as opposed to the fixed costs of enforcement usually considered in the literature, drastically modifies the outcome of the game. Cooperation may break down if these costs are too high. If cooperation occurs, the group chooses a level of appropriation that lies somewhere between the non-cooperative level and the costless (or fixed-cost) cooperative level. The level of overappropriation thus obtained is an increasing function of the unit costs of enforcement and of the benefits from defaulting. This helps explain why cooperating communities with similar primitives and facing identical market conditions may choose different levels of resource appropriation. Among cooperating communities, the quality of cooperation will thus improve with policy interventions that help reduce the variable costs of cooperation.

This includes any activity that improves the flow of information for monitoring and the ability to enforce rules, for instance through the formation of sub-coalitions, improved leadership, or enhanced social norms and social capital.

We then analyzed how heterogeneity among producers, who differ either in their efficiency in production or in their stocking capacity (with one herder being constrained in his herd size), affects the group's optimal behavior, a subject on which there has been much controversy. We show that the less efficient producer and the constrained producer would always benefit from the group choosing cooperation. The more efficient producer and the non-constrained producer always benefit less from cooperation, and may even lose if cooperation is imposed. We then restrict the feasibility of cooperation to choice of an appropriation strategy that ensures that both producers individually gain in profit (without allowing for side payments). We find that if heterogeneity is too high (differentials in efficiency levels are too large, or the stocking constraint on one herder is too tight), cooperation may break down. At lower levels of heterogeneity, cooperation is feasible. Policy interventions that reduce social differentiation within the community are thus favorable to cooperation, for instance by boosting the efficiency of laggards through technical assistance and relaxing constraints on stocking due to selective lack of access to credit. Hence, while social differentiation under a private property regime may help increase aggregate efficiency by letting the more efficient producers displace the less efficient ones through the workings of the land market, this is not the case under common property where the breakdown of cooperation due to excessive social differentiation is a source of inefficiency.

The two types of heterogeneity however differ in their impact on the level of overappropriation : with heterogeneity in production costs, the cooperative level (if acceptable) is not affected by inequality in efficiency; while, with asymmetric capacity constraints, the level of overappropriation decreases as the constraint becomes tighter. The non-cooperative level of overappropriation is also unaffected by heterogeneity in production costs, but decreases as one herder experiences a more severe capacity constraint. Hence, relaxing the constraint on capacity that applies to some members, for instance through targeted credit programs, helps reduce overappropriation by favoring cooperation, but increases overappropriation once cooperation has been achieved.

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