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COMMON POOL RESOURCE APPROPRIATION UNDER COSTLY COOPERATION

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Common Pool Resource Appropriation under Costly Cooperation[1]

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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. These variable costs are assumed to be an increasing function of individual members' incentives to default. This allows to explain why we commonly observe different qualities of cooperation across otherwise identical communities. It also allows to explain why heterogeneity in production efficiency across members or in their constraints on capacity to extract affect the feasibility and eventually the quality of cooperation, a subject on which there has been much debate in the literature.

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1. 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.[2] 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.

In recent years, however, a number of observers such as Ostrom (1992), Bromley (1992), and Baland and Platteau (1996) 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 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, 1993). These particular payoff structures, however, characterize only a subset of rather specific situations of CPR appropriation.

The second interpretation is to rely 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 hardly applicable to explain community behavior: in most traditional communities, exclusion from the CPR is not credible and reverting to non-cooperation when many members are involved would be too costly to too many others to be credible. A third interpretation is consequently needed. Much of the descriptive literature examining the successful use of common-pool resources has focused on the ability of the group as a whole to communicate and cooperate, allowing members to devise a system of governance to regulate use of the resource (c.f., Ostrom, 1992; McKean, 1992; Bromley, 1992). Thus, the third and most appealing interpretation calls upon analyses of group-level cooperation resulting in the definition of rules, the monitoring of member behavior, and the enforcement of agreed upon rules. In the literature on

[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).

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.[3] Hence, cooperation is a binary decision, and all cooperative levels should be identical for communities with identical primitives (resource endowments, technology, and objective functions) and identical market conditions.[4]

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 expected individual gains from cooperation: A resource with well defined boundaries and a well defined set of users that can easily protect the resource from encroachment from outsiders (Ostrom, 1992; Wade, 1987), a smaller number of members over which to distribute the gains from cooperation (Olson, 1965; Bendor and Mookherjee, 1987), and resource abundance that is neither too high nor too low (Bardhan, 1993).

(2) Lower monitoring costs: Smaller groups, greater proximity and homogeneity of members (Wade, 1987), and members who have been longer together (Hirschman, 1970).

(3) Increase the ability to enforce rules: Effective leadership, high cost of exit option (Hirschman, 1970), homogeneity and perception of fairness in the distribution of the gains from cooperation (Johnson and Liebcap, 1982), interlinkages among community members (Besley and Coate, 1995), credibility of threats and commitment to sanction, availability of conflict resolution mechanisms (Ostrom, 1992), shared social norms (Sethi and Somanathan, 1996), and a high stock of 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 and market conditions 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. We hypothesize a simple formulation of community supervision behavior that leads to costs of enforcing

[3] Baland and Platteau (1996; chapter. 12) note that "in many non-cooperative games there exist a plethora of possible equilibria" so that collective action may be necessary in order to settle on the "best" equilibria. However, with imperfect information, there is a great deal of scope for individuals to manipulate information to their advantage. In this case, the activities of the group are to provide a clearing-house so that the most efficient outcome – which theoretically can be supported by decentralized, individual strategies with perfect information – can be reached. That is to say, once cooperation has been established, there is no reason why the most efficient outcome will not be reached.

[4] Note that we are analyzing the appropriation decisions of a well-defined group over a CPR. This is opposed to analyses that take into account transactions costs that are a function of the number of members, and therefore change at the margin when the number of members is a choice variable (c.f., Sandler, 1992).

the cooperative agreement that are an increasing function of the incentives to default. Formalizing a model of cooperative behavior under variable costs of cooperation opens a vast field of reinterpretation of observed cooperative behavior. 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.

The role of heterogeneity on cooperation has been extensively debated in the literature. Heterogeneity has been associated both with poor cooperative performance (Ostrom, 1993; Kanbur, 1992) and with successful performance (Olson, 1965; Baland and Platteau, 1997 and 1998). 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, both heterogeneity in costs and in capacity constraints restrict the ability to find an acceptable cooperative solution. Where an interior solution can be reached, heterogeneity in production costs does not affect the level of over-appropriation, whereas heterogeneity of capacity constraints reduces the level of over-appropriation.

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. 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 5 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 pool 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 out externality captures the negative effect of adding an additional head of cattle on total weight gain for all animals stocked. However, each individual i only internalizes that portion of the negative externality accruing to him. The profit from grazing is written:

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

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 gain function (see Hart et al., 1989), 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:

$$n_i^{\bullet}(n_j) = \text{argmax}\ \pi_i = \frac{a-\tilde{c}/p}{2b}H - \frac{n_j}{2}, \quad i, j = 1,2, \quad i \neq j.$$

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

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

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 common pool resources. However, 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 reached if the group undertakes costly monitoring and enforcement measures.

Incentives to cooperate or to defect and costs 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 n:

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

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 to the agreement (given that the other person cooperates):

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

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

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

Figure 1 illustrates these incentives and choices. Incentives to cooperate and to cheat are null at the non-cooperative level n^{-}. 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.

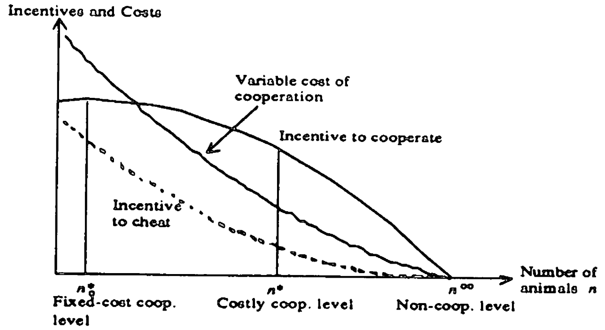


Figure 1. Incentives to cooperate and not-cooperate

We assume that the enforcement costs necessary to ensure cooperation include some fixed costs Γ and variable costs that increase with the incentives to cheat. The underlying mechanism by which we obtain this relationship for the variable costs is the following. Suppose that enforcement of cooperation requires explicit costs of observing individual behavior (this is for example the case when the number of animals grazing in large communal land has to be checked). The more effort the community puts into this supervision, the highest is the probability that any cheating individual will be caught. If C_i are the expenses on supervision of individual i, $p(C_i)$ the probability of being caught if cheating, and P the penalty if caught cheating, then individual i will choose not to cheat if and only if:

$$(1 - p(C_i))I_i^{Ch} - p(C_i)P > 0.$$

This defines the minimum level of expenditures that the community has to spend to prevent i from cheating. It is an increasing function of the incentive to cheat I_i^{Ch}. While there may be some economies of scale in supervising members of the community, we can assume that the overall minimum expenditure that the community has to expend to ensure cooperation by all members is of the form:

$$\Gamma + \gamma \sum_i I_i^{Ch},$$

where γ is the unit enforcement cost. 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 have in cheating. The cost parameters Γ and γ 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 maximization of the 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.[5] The cooperative solution n^* is enforceable without explicit transfer only if there is a positive profit gain from cooperation, $\pi_i(n^*, n^*) \geq \pi_i(n^{-*}, n^{-})$, for each producer i. Hence the group's cooperative behavior is given by:

$$\begin{aligned} n^* = \arg\max_n & \left\{ W = \sum_i \left[\pi_i(n, n) - \pi_i\left(n^{-}, n^{-}\right)\right] - \gamma \sum_i I_i^{Ch} - \Gamma \right\} \\ \text{s.t. } & \pi_i(n, n) \geq \pi_i\left(n^{-}, n^{-}\right), \; i = 1,2 \\ & W \geq 0. \end{aligned} \tag{2}$$

Solution of the problem gives the enforceable cooperative solution:

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

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

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

is the maximum fixed cost that the community can bear without abandoning cooperation.

We represent on Figure 1 the variable cost of cooperation (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). The optimal level of cooperation n^* is obtained when these marginal effects balance each others.

[5] Disregarding the possibility of secondary transfers is classical in the literature on local cooperative behavior. See Ostrom and Gardner (1993) and Seabright (1993). In the symmetric case presented here, no solution would involve transfer, but the assumption will be necessary for the asymmetric cases discussed in the next two sections.

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:

$$n_\infty^\circ = \frac{a-\bar{c}/p}{4b}H \le n^\circ \le n^{\infty} = \frac{a-\bar{c}/p}{3b}H.$$

This gives the range of variation for the rate of overgrazing: $1 \le \eta \le 4/3$.

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

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

and the overall welfare is:

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

Comparative static on the cooperative solution

Expression (3) shows that overgrazing increases with the unit cost 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 cheat, and the overall welfare gain from cooperation (5) are all increasing with $p\frac{(a-\bar{c}/p)^2}{b}H$. 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.

To summarize, the model developed above provides a framework for analyzing group-level appropriation decisions. The model is novel in its ability to explain two frequently observed characteristics of common-pool resource management: agreements (both formal and informal) that are undertaken and enforced at the level of the group as a whole, and equilibrium appropriation levels that are between the fixed-cost cooperation and the Nash non-cooperative solutions. The idea of partial or imperfect cooperation has been expressed by a number of authors, though most of the empirical evidence is anecdotal (Baland and Platteau, 1996; Ostrom, 1992; Oakerson, 1992). In fact, Baland and Platteau state that: "It is perhaps too simplistic to view the experiences of common property management in terms of outright failure or success in cooperating across communities. It is likely that a good number of these experiences are only partially successful" (Baland and Platteau, 1996, Chapter 12, pg. 285). Three studies which attempt to measure the extent of cooperation show varying degrees of success. In Lopez (1992) and Ahuja (1996), 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. Results from both studies suggest that communities cooperate at different levels, and that in general the degree of success in management lies between outcomes associated either with non-cooperative or fixed-cost cooperative behavior. In McCarthy et al. (1998), the authors estimate stocking rates across nine Mexican communities. 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 gives a better fit than a dichotomous cooperate/not cooperate specification, indicating that there are indeed different levels of cooperation among communities.

As with other factors hypothesized to affect the successfulness of common pool resource regulation, greater "heterogeneity" has been associated with both poor and successful management performance. Baland and Platteau (1997) analyze different types of heterogeneity: heterogeneity in interests (multiple uses), heterogeneity in socio-cultural norms, and 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 characterizing each producer, or in a constraint on stocking levels that is binding for only one producer. To simplify the presentation, we will ignore any fixed cost of cooperation.

3. Heterogeneity in production costs

Suppose now that the two herders have differential production costs, with herder 1 less efficient than herder 2, i.e., $c_1 > c_2$. We consider a mean preserving spread of the cost of production, with $c_1 = \bar{c} + \delta$ and $c_2 = \bar{c} - \delta$, where δ measures heterogeneity.

Non-cooperative solution

The non-cooperative reaction function of producer *i* is:

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

and the non-cooperative equilibrium is:

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

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

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

and individual profits are:

$$\pi_i^{nc} = \pi_i\left(n_1^{nc}, n_2^{nc}\right) = \frac{bp}{H}\left(n_i^{nc}\right)^2.$$

Because of the constant marginal cost assumption, the total number of animals N^{oo} only depends on average cost and hence is the same as when herders are homogenous in production costs. 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.

Participation and welfare constraints

We only consider the symmetric solution in which both producers have equal grazing rights. We can show that the profit gain from cooperation is larger for the high cost producer,

$$\pi_1(n,\ n) - \pi_1^{-} > \pi_2(n,\ n) - \pi_2^{-},$$

if and only if $n < \frac{2}{3}\frac{a - \bar{c}/p}{b}H$, which we will see later the solution always satisfies. The participation constraint to accept cooperation,

$$\pi_i(n,\ n) - \pi_i(n_1^{-},\ n_2^{-}) = \frac{bp}{H}n\left(\frac{a - c_i/p}{b}H - 2n\right) - \frac{bp}{H}n_i^{-2} \geq 0,$$

only needs be imposed for the low cost producer $i = 2$. This is because the low cost producer had more animals under non-cooperation and hence will have to reduce his herd size under cooperation by more than the high cost producer.

Note first that this constraint has no solution for

$$\delta \geq \delta_{max} = \frac{3 - 2\sqrt{2}}{2\sqrt{2} - 1}\frac{ap - \bar{c}}{3},$$

that is for levels of heterogeneity that are too high. For lower levels of heterogeneity, $\delta \leq \delta_{max}$, the constraint can be written:

$$\frac{a - \bar{c}/p}{4b}Hg_{min}(\delta) < n < \frac{a - \bar{c}/p}{4b}Hg_{max}(\delta),$$

with $g_{min}(\delta) = 1 + \frac{\delta}{ap-\bar{c}} - \sqrt{\left(1 + \frac{\delta}{ap-\bar{c}}\right)^2 - \frac{8}{9}\left(1 + 3\frac{\delta}{ap-\bar{c}}\right)^2}$, increasing function of δ,

and $g_{max}(\delta) = 1 + \frac{\delta}{ap-\bar{c}} + \sqrt{\left(1 + \frac{\delta}{ap-\bar{c}}\right)^2 - \frac{8}{9}\left(1 + 3\frac{\delta}{ap-\bar{c}}\right)^2}$, decreasing function of δ.

This means that the low cost producer will not find it profitable to abide by 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 are large differences in production costs and hence in non-cooperative herd sizes.

The welfare gain from cooperation

$$W = \sum_i \left[\pi_i(n, n) - \pi_i\left(n^{-}, n^{-}\right)\right] - \gamma \sum_i f_i^{Ch}$$

is a quadratic function in n, which is positive for values of n between the two roots $\frac{a - \bar{c}/p}{4b} Hf$:

$$\frac{a - \bar{c}/p}{4b} Hf_{\min}(\gamma, \delta) < n < \frac{a - \bar{c}/p}{4b} Hf_{\max}(\gamma, \delta).$$

We can show that $f_{\min}(\gamma, \delta)$ is an increasing function of γ.

Constrained optimal solution

The optimal cooperative solution under the participation and welfare constraints is:

$$n^* = \arg\max_n W$$

$$\text{s.t. } \pi_i(n, n) \geq \pi_i\left(n_1^{-}, n_2^{-}\right), \; i = 1,2, \text{ and } W \geq 0$$

The interior solution for the maximum welfare is $n = \frac{a - \bar{c}/p}{4b} H\eta(\gamma)$, where $\eta(\gamma) = \frac{1 + \frac{3}{2}\gamma}{1 + \frac{9}{8}\gamma} \geq 1$. It is an increasing function of γ. For a given δ, as the cost of enforcement γ increases, the constrained optimum is the following:

a) If $\eta(\gamma) < g_{\min}(\delta)$, then $n^* = \frac{a - \bar{c}/p}{4b} Hg_{\min}(\delta)$. This can only happen for large values of heterogeneity and low values of enforcement cost.

b) If $g_{\min}(\delta) < \eta(\gamma) < g_{\max}(\delta)$, then the interior solution satisfies both constraints, and it is the optimal solution $n^* = \frac{a - \bar{c}/p}{4b} \eta(\gamma)$.

c) If $f_{\min}(\gamma, \delta) < g_{\max}(\delta) < \eta(\gamma)$, then $n^* = n^*_{\max} = \frac{a - \bar{c}/p}{4b} Hg_{\max}(\delta)$.

d) If $f_{\min}(\gamma, \delta) > g_{\max}(\delta)$, then there is no cooperative solution that leads to a positive welfare.

These results are interpreted in Figure 2 which shows the influence of the enforcement cost on the equilibrium aggregate stocking rate N^*, at different levels of heterogeneity. Let us for now disregrad the case of very low enforcement costs and very high inequality (case a above). When enforcement cost is zero, at A, cooperative behavior is chosen and the aggregate stocking rate is equal to the fixed-cost level N_o^*. As enforcement cost increases, the optimum cooperative stocking rate increases along the curve A´B´. With higher enforcement cost, at B, and a correspondingly higher level of stocking rate, the benefit to the low cost producer falls to 0, although profit to herder 1 and aggregate welfare are still positive. The optimum group behavior is to maintain the grazing rate at this limit level (segment B´C´). With yet higher enforcement cost, the aggregate welfare of cooperation falls to zero and cooperation breaks down (D´E´). With a higher level of heterogeneity δ, the breakdown of cooperation occurs at a lower level of enforcement cost (path A´F´G´H´E´). In the case of very high inequality, the lowest point A´ is not reached and the path is A′′F′G′H′E′. When herders are identical (δ = 0), the cooperative level tends gradually to the non-cooperative level as enforcement cost increases (curve A′E′).

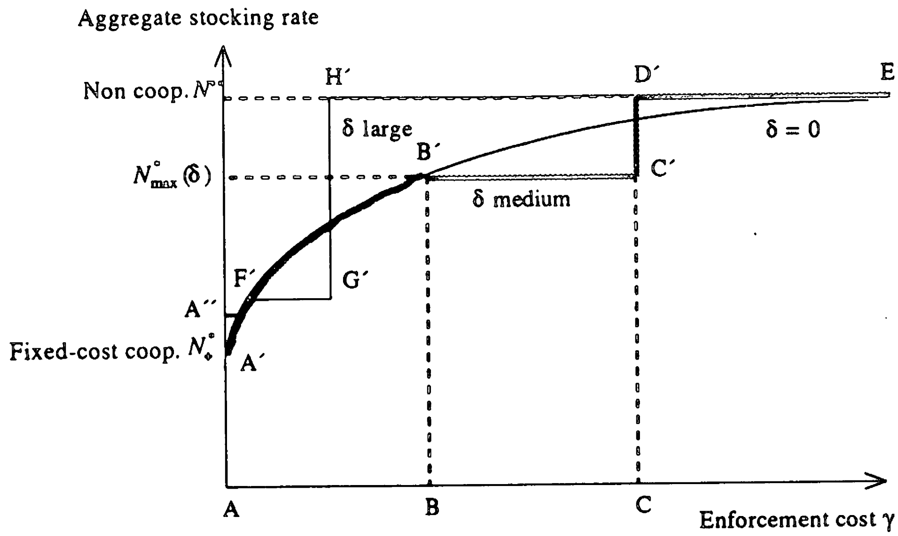


Figure 2. Aggregate stocking rate with heterogeneity in production costs

We thus find that heterogeneity influences the limit to cooperation, but not the level of cooperation for the interior solution (on curve A′B′). This is to say that, when comparing a community whose members are heterogenous with another community whose members are homogenous in terms of marginal costs but have the same average cost, total stocking rates will be the same in the two communities for as long as they cooperate. Note that similar results obtain for the non-cooperative game: the extent of overstocking and the welfare losses to producers under both group cooperation and non-cooperation are the same whether or not members are homogeneous.

An interior solution to 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 enforcing cooperation, or 2) unit costs of cooperation are too high. Again, the high-cost member will always gain from enforcement of stocking levels lower than those that obtain at the non-cooperative equilibrium. However, the low-cost producer will always gain less, and may even lose.

It is interesting to combine this result with those from section 2 where producers were homogenous, to analyze the impact on cooperation of a decrease in production costs. As mentioned in the introduction, there is some confusion as to whether changes that make exploitation of a common pool 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 become 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 group cooperation will not be feasible. Cooperation may in fact break down with rising heterogeneity in production efficiency across community members, resulting in over appropriation of the resource and lower profits for the group as a whole.

4. Heterogeneity in stocking capacity

Assume now 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[6] but not in the cooperative equilibrium (to be determined), i.e., $\bar{n}_1 > n^*$. If herder 1 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:

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

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:

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

As the constraint on the number of animals herder 1 can acquire becomes tighter, i.e., $\bar{n}_1$ decreases from the maximum n^{**} he would wish to acquire to zero, the non-cooperative solution $N_{cons.}^{**}$ 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.

As previously, we only consider cooperative solutions that give equal grazing rights to the two herders.

Participation and welfare constraints

Regarding the participation and positive welfare constraints,

[6] Having the herder 1 constrained in his incentive to cheat is sufficient to alter the equilibrium, even if he is not constrained in the non-cooperative equilibrium. But, for simplicity, we carry on the analytics when the constraint binds in the non-cooperative equilibrium.

$$\pi_i(n, n) \geq \pi_i(n_1^{*}, n_2^{*}),\ i = 1,2, \text{ and } W \geq 0,$$

we can show that:

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

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

Hence the participation constraint needs only be imposed for unconstrained herder 2.

b) Unconstrained herder 2 chooses not to cooperate if herder 1 is severely constrained. This is shown as follows. The profit gain from cooperation for herder 2 is a quadratic expression in n and $\bar{n}_1$:

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

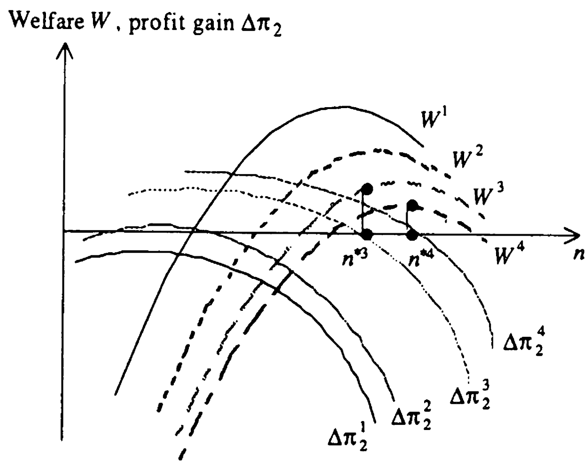
This expression is always negative for values of the constraint $\bar{n}_1 < \bar{n}_{1\min} = \left(1 - \frac{\sqrt{2}}{2}\right)\frac{a-\bar{c}/p}{b} H$.

Hence, if herder 1 faces a very tight limit on his herd size, 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 levels of the constraint $\bar{n}_1$.

c) Welfare is also a quadratic expression in n and $\bar{n}_1$:

$$W = \frac{bp}{H}\left[(1+\gamma)2n(\alpha - 2n) - \gamma\left[\bar{n}_1(\alpha - n - \bar{n}_1) + \left(\frac{\alpha - n}{2}\right)^2\right] - \left(\frac{\alpha^2 - \bar{n}_1^2}{4}\right)\right],$$

where $\alpha = \frac{a-\bar{c}/p}{b} H$. For the range of values considered for $\bar{n}_1$, W always has two roots and 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 welfare W is a decreasing function of the enforcement cost, while the profit gain $\Delta\pi_2$ is independent of the enforcement cost. For low values of $\bar{n}_1$, there is no value of n that yields both positive profit and welfare. Let $\bar{n}_0$ be the value of the constraint $\bar{n}_1$ for which the largest root of $\Delta\pi_2$ and the smallest root of W are equal.



The curves $\Delta\pi_2^i$ and W^i, $i = 1,\ldots,4$, correspond to increasing values for the constraint level $\bar{n}_1^1 < \bar{n}_1^2 < \bar{n}_1^3 < \bar{n}_1^4$.

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

Constrained optimal solution

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

a) At very low level of $\bar{n}_1$, $\bar{n}_1 < \bar{n}_{1\min}$, 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 levels of n.

b) At higher levels, $\bar{n}_{1\min} < \bar{n}_1 < \bar{n}_0$, profits for herder 2 will only be positive for low levels of n. But then, the incentives to cheat and hence the enforcement costs are high enough so as to make overall welfare negative. Hence, no solution can both satisfy the unconstrained herder's participation constraint and lead to a positive welfare. This is illustrated for $\bar{n}_1^2$ in Figure 3.

c) If $\bar{n}_1 > \bar{n}_0$, there is a range of values for n that satisfy both positive profit and welfare constraints which, however, does not include the value that maximize welfare. The constrained cooperative solution is thus the maximum value acceptable by herder 2,

$$n^* = \frac{a-\bar{c}/p}{4b}H + \frac{1}{4}\sqrt{\left(\frac{a-\bar{c}/p}{b}H\right)^2 - 2\left(\frac{a-\bar{c}/p}{b}H - \bar{n}_1\right)^2}\,. \tag{6}$$

One can verify that n^* is lower than $\bar{n}_1$. This corresponds to case $\bar{n}_1^3$ in Figure 3 with the cooperative equilibrium at n^{*3}.

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

$$\overset{\circ}{n}_{cons.} = \frac{a - \bar{c}/p}{4b} H\left[\frac{1+\frac{5}{4}\gamma}{1+\frac{17}{16}\gamma}\right] + \frac{\bar{n}_1}{8}\frac{\gamma}{1+\frac{17}{16}\gamma}. \qquad (7)$$

This optimal cooperative stocking rate increases with the enforcement cost γ, like in the basic model. It is smaller than the constrained value $\bar{n}_1$ if and only if $\frac{a-\bar{c}/p}{4b}\frac{1+\frac{5}{4}\gamma}{1+\frac{15}{16}\gamma} < \bar{n}_1$. Hence, if enforcement costs are too high, cooperation is not possible.

e) The constraint is binding only if the optimal cheating level for herder 1 is larger than the capacity constraint:

$$n_1^{\bullet}(n^*) = \frac{a-\bar{c}/p}{2b} H - \frac{n^*}{2} \geq \bar{n}_1 .$$

This sets the maximum level $\bar{n}_{1\max}$ for $\bar{n}_1$ beyond which the constraint is not binding:

$$\bar{n}_{1\max} = \frac{a-\bar{c}/p}{4b} H \frac{3}{2}\frac{1+\gamma}{1+\frac{17}{16}\gamma}.$$

Beyond this point, the community returns to the unconstrained cooperative solution.

The path of the equilibrium solution for the aggregate stocking rate as the level of the constraint for herder 1 varies is represented on Figure 4. There are four reference levels for the total stocking rate: 1) the fixed cost cooperative equilibrium AA´, which is the most efficient cooperative level N_{-}^{*}; 2) the non-cooperative constrained equilibrium $N_{cons.}^{**}$ along curve BB´; 3) the cooperative equilibrium when there is no capacity constraint along path GG´ (corresponding to the basic model in section 2, equation (3)); and 4) the constrained cooperative equilibrium from equation (7) above. In addition, we have represented the curve of zero profit for herder 2, $\Delta\pi_2 = 0$, and zero aggregate welfare, $W = 0$. We start the description of the path from the lowest value for the capacity constraint on herder 1. If herder 1 has no capacity to stock ($\bar{n}_1 = 0$), herder 2 grazes the economic optimal number of animals N_{-}^{*} (point A on Figure 4). As herder 1 starts to graze animals, although he is still very constrained ($\bar{n}_1 < \bar{n}_0$) there is no cooperation, and the total number of cattle increases (segment ABC). This range includes an interval over which it is never profitable for herder 2 to cooperate (when $\bar{n}_1 < \bar{n}_{1\min}$) and a range where there is no level of cooperation that leads to both positive profit for herder 2 and overall positive welfare (for $\bar{n}_{1\min} < \bar{n}_1 < \bar{n}_0$). As the constraint reaches the value $\bar{n}_0$, cooperation becomes feasible, along the curve of zero profit for herder 2 (segment DE). As the capacity constraint relaxes further, we obtain the interior solution of the constrained optimization of welfare (segment EF) until we reach a level beyond which the constraint is no longer effective. The herders then switch to the unconstrained optimum (segment GH)

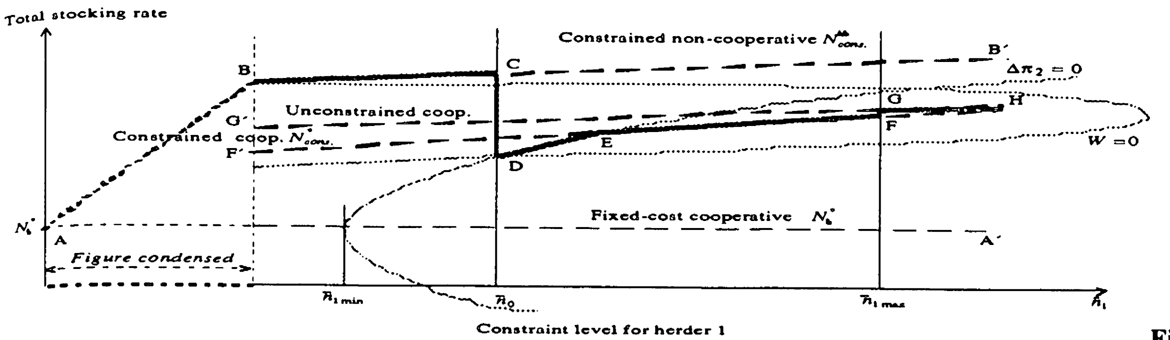


Figure 4 . **Path of total stocking rate as the stocking constraint changes**

5. Conclusion

We have developed a theory of cooperation in which we assume that the costs of monitoring the behavior of community members and enforcing the agreed upon rules for appropriation of the CPR depend on the incentives that members have to defect (I_i^{Ch}) and on unit costs that capture the group's ability to monitor and enforce its rules (γ). 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. Like 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 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.

Furthermore, improved profitability -- when players are homogeneous -- leads to greater gains from cooperation. Because increases in profitability affect all incentives in the same manner -- i.e., incentives to cooperate as well as incentives to deviate -- the degree of over-appropriation does not change. The model is highly stylized, but this is an interesting result that contradicts much of the current thinking on common-pool resource management. If increased market access only reduces transactions costs and increases effective prices received, then we should not expect either the discrete decision on cooperation nor the quality of cooperation to change. Yet, if increased market access is also accompanied by an increase in "exit" options for community members, a decrease in the power of traditional authorities, and/or the opportunity costs of members' time allocated to resource management, then, overall, the effect may be to reduce the quality of cooperation by shifting the unit costs of cooperation. The point is, however, that these differential effects need to be sorted out in empirical analyses; factors affecting unit costs of enforcement must be separated out from factors affecting incentives directly.

We analyzed how heterogeneity among producers, who differ either in their production efficiency 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 loose when 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.

The two types of heterogeneity, however, differ in their impact on the level of over-appropriation: with heterogeneity in linear production costs, the cooperative level (if acceptable) is not affected by inequality in efficiency; while, with asymmetric capacity constraints, the level of over-appropriation is affected by the constraint. The non-cooperative level of over-appropriation 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 over-appropriation by favoring cooperation.

A policy recommendation that derives from this analysis is to make the less efficient or more constrained players more capable of inflicting losses on the other members if cooperation is not reached. In the case where the constraint precludes a group-cooperative outcome, it is because the unconstrained herder has relatively high profits under non-cooperation so that no agreement on total stock levels that allocate grazing rights equally can leave this herder as well off as he is under non-cooperation. In a sense, a less binding constraint means that herder 1 can increase his credibility to threaten to cause lower profits under non-cooperation, so that a group-cooperation solution is more likely.

Policy interventions that reduce social differentiation within the community are thus favorable to cooperation, for instance by boosting the efficiency of the less efficient 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 among community members is a source of inefficiency.

References

Ahuja, V. 1996. "Land Degradation, Agricultural Productivity and Common Property: Evidence from Côte d'Ivoire. World Bank, Washington DC (mimeo).

Baland, Jean-Marie and Jean-Philippe Platteau. 1996. *Halting Degradation of Natural Resources: Is There a Role for Rural Communities?* Cambridge University Press.

Baland, Jean-Marie and Jean-Philippe Platteau. 1997. "Wealth Inequality and Efficiency in the Commons. The Unregulated Case". *Oxford Economic Papers* 49(4):451-482.

Baland, Jean-Marie and Jean-Philippe Platteau. 1998. "Wealth Inequality and Efficiency in the Commons. The Regulated Case". *Oxford Economic Papers* 50(1):1-22.

Bardhan, Pranab. 1993. "Analytics of the Institutions of Informal Cooperation in Rural Development". *World Development*, 21(4): 633-40.

Bendor, J. and D. Mookherjee. 1987. "Institutional Structure and the Logic of Ongoing Collective Action". *American Political Science Review*, 81(1): 129-54.

Besley, Timothy and S. Coate. 1995. "Group Lending, Repayment Incentives and Social Collateral". *Journal of Development Economics*, 46(1) :1-18.

Bromley, Daniel. 1992. *Making the Commons Work: Theory, Practice, and Policy.* San Francisco: Institute for Contemporary Studies Press.

de Janvry, Alain, Nancy McCarthy, and Elisabeth Sadoulet. 1998. "Endogenous Provision and Appropriation in the Commons". Paper presented at the Allied Social Science Association meeting, Chicago.

Hart, R. H., Marilyn Samuel, Peter Test, and Michael Smith. 1989. "Cattle, Vegetation, and Economic Responses to Grazing System and Grazing Pressure". *Journal of Range Management*, 41 (4): 282-287.

Hirschman, Albert. 1970. *Exit, Voice, and Loyalty.* Cambridge: Harvard University Press.

Johnson, Ronald and Gary Liebcap. 1982. "Contracting Problems and Regulation: The Case of the Fishery". *American Economic Review*, 72(5): 1005-22.

Kanbur, Ravi. 1992. "Heterogeneity, Distribution, and Cooperation in Common Property Resource Management". Policy Research Working Papers WPS 844, The World Bank, Washington D. C.

Lopez, R. 1992. "Resource Degradation, Community Controls and Agricultural Productivity in Tropical Areas". University of Maryland, College Park, MD (mimeo).

McCarthy, Nancy, Alain de Janvry, and Elisabeth Sadoulet. 1998. "Land Allocation Under Dual Individual-Collective Use in Mexico". *Journal of Development Economics*, forthcoming.

McKean, Margaret. 1992. "Management of Traditional Common Lands (*Iriaichi*) in Japan". in D. Bromley, ed., *Making the Commons Work: Theory, Practice, and Policy.* San Francisco: Institute for Contemporary Studies Press.

Oakerson, R. 1992. "Analyzing the Commons: A Framework". Chapter 3. In: Bromley, Daniel (ed.), *Making the Commons Work: Theory, Practice, and Policy.* San Francisco: Institute for Contemporary Studies Press.

Olson, Mancur. 1965. *The Logic of Collective Action: Public Goods and the Theory of Groups.* Cambridge, MA: Harvard University Press.

Ostrom, Elinor. 1992. *Governing the Commons: The Evolution of Institutions for Collective Action.* New York: Cambridge University Press.

Ostrom, Elinor. 1993. "Coping with Asymmetries in the Commons: Self-Governing Irrigation Systems Can Work". *Journal of Economic Perspectives,* 7(4): 93-112.

Ostrom, Elinor, and Roy Gardner. 1993. "Coping with Asymmetries in the Commons: Self-Governing Irrigation Systems Can Work". *Journal of Economic Perspectives,* 7(4):93-112.

Sandler, Todd. 1992. *Collective Action: Theory and Applications.* Ann Arbor: University of Michigan Press.

Seabright, Paul. 1993. "Managing Local Commons: Theoretical Issues in Incentive Design". *Journal of Economic Perspectives,* 7(4): 113-34.

Seabright, Paul. 1994. "Is Cooperation Habit Forming?". In Dasgupta, P. and K. G. Maler, eds., *The Environment and Emerging Development Issues.* Oxford: Clarendon Press.

Sethi, Rajiv and E. Somanathan. 1996. "The Evolution of Social Norms in Common Property Resource Use". *American Economic Review,* 86(4): 766-88.

Wade, Robert. 1987. *Village Republics: Economic Conditions for Collective Action in South India.* Cambridge: Cambridge University Press.