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# Inequality and conservation on the local commons: A theoretical exercise<sup>1</sup>

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## Abstract

To analyze the effect of asset inequality on cooperation within a group, we consider a two-player noncooperative model of conservation of a common-pool resource (CPR): a fishery. We give necessary and sufficient conditions such that conservation is a Nash equilibrium, and we show that increasing inequality does not, in general, favor full conservation. However, once inequality is sufficiently great, further inequality may push the players closer to efficiency. Thus the relationship between inequality and economic efficiency is U-shaped. We analyze the implications for conservation if players have earning opportunities outside the commons. Finally, we consider various schemes of community regulation of the commons in the light of the noncooperative model with or without exit options. We find that increases in inequality may restrict the range of implementable mechanisms.

*keywords:* collective action, common property, exit options, inequality

*JEL classification codes:* D63, D71, H41, O12, O13, Q22, Q25

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# 1 Introduction

The daily livelihood of vast masses of the rural poor in many countries depends on the success with which *common pool resources* (CPRs) — such as forest resources, grazing lands, in-shore fisheries, and irrigation water — are managed, and on the environmental consequences of their management. A CPR is defined by Ostrom (1990, p. 30) as “a natural or man-made resource system that is sufficiently large as to make it costly (but not impossible) to exclude potential beneficiaries from obtaining benefits from its use.” Understanding the factors which lead to success or failure of community management of these resources is critical to rural development.

CPR management is a collective action dilemma: a situation in which mutual cooperation is collectively rational for a group as a whole, but individual cooperation may not be individually rational for each member. One factor which has not always been recognized as critical to the outcome of collective action dilemmas is heterogeneity among the players. Ostrom (1990), whose analysis of local management of CPRs is probably the best-known, discusses homogeneity and heterogeneity but excludes the issue from her list of factors crucial to successful CPR management. In this paper, our attention will be largely restricted to a single but potent kind of heterogeneity: asset inequality.

Olson (1965, p. 34) hypothesized that inequality may be beneficial to the provision of a public good:

In smaller groups marked by considerable degrees of inequality – that is, in groups of members of unequal “size” or extent of interest in the collective good – there is the greatest likelihood that a collective good will be provided; for the greater the interest in the collective good of any single member, the greater the likelihood that that member will get such a significant proportion of the total benefit from the collective good that he will gain from seeing that the good is provided, even if he has to pay all of the cost himself.

Inequality in this context can thus facilitate the provision of the collective good, with the small players free-riding on the contribution of the large player. In a very general setting, Bergstrom, Blume and Varian (1986) show that wealth redistributions which increase the wealth of equilibrium contributors to a public good will increase the supply of the public good.<sup>4</sup> These analyses of the

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<sup>4</sup>Chan, Mestelman, Moir, and Muller (1996) report that when the Bergstrom-Blume-Varian model is tested in the laboratory, it correctly predicts the direction (though not the magnitude) of changes in group contributions when income is redistributed toward positive contributors. It does not do so well in predicting individual behavior: individuals with low incomes overcontribute to the public good, and high-income individuals undercontribute, relative to the model.

supply of public goods are relevant to conservation among CPR users. Restraint in resource use is analytically equivalent to contributing to a public good. Following these studies, we would expect group heterogeneity to be conducive to the effective management of CPRs.<sup>5</sup>

Nevertheless, field studies of CPR management have repeatedly shown that inequality may be harmful for collective action (see especially the discussion in Baland and Platteau, 1996). Johnson and Libecap's (1982) study of the Texas shrimp fishery is a well-known example. The fishery is exploited by a large fleet of fishers differentiated by ability. The problem is one of overfishing: in this case of increased effort and declining per-boat yields, there exists a collective incentive to self-regulate effort, in the form of production quotas, and thereby increase collective rents. The success of such contracting, however, is conditioned by the existence of high transaction costs. Johnson and Libecap assume that side-payments are impossible to administer, and that the information costs (and, presumably, enforcement costs) underlying agent-specific quotas are too high to make such a quota system practical; the only option, therefore, is a system of uniform quotas. The per-agent gain in moving from the unregulated equilibrium to the rent-maximizing output level (under uniform quotas) is the same for all agents, but the per-agent loss is increasing in agents' productivity. Thus it is possible that more productive fishers stand to lose under a cooperative regime, and hence they will oppose it.

A small group of papers has sought to formalize the logic of the Johnson and Libecap example. Kanbur (1991) describes a two-person, simultaneous-move numerical example in which the players have different payoff functions. As payoff inequality is increased, the cooperative outcome ceases to be a self-enforcing equilibrium. Bardhan (1995) reviews the case-study literature regarding the relationship between inequality and cooperation in locally-managed irrigation systems, primarily in Asia. Baland and Platteau (1997) likewise summarize many relevant examples from the case-study literature; they focus more on forests, fisheries and grazing lands, and on African cases. Baland and Platteau argue that inequality in resource-use entitlements is associated with higher conservation in some examples where the resource-use technology (i.e., fishing, harvesting, gathering) exhibits decreasing returns to effort. Under alternative cases featuring increasing returns to effort, the effect of increased inequality is ambiguous.

This paper presents a model of heterogeneous resource users in a local commons dilemma where the source of the heterogeneity is asset inequality. The model is couched in terms of a fishery; in part,

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<sup>5</sup>There exists a sociological literature on this subject. Heckathorn (1993: see also the references therein to work by Oliver and Marwell) summarizes and extends the sociological models of inequality and collective action, suggesting that the effect of inequality is more complicated than is envisioned in the economics papers discussed above. Unfortunately, these sociological models take as given parameters which, for our purposes, should be outcomes.

this is because the crisis of fisheries globally (see, e.g., Safina (1995)) may be more advanced than resource degradation associated with other CPRs. Nevertheless, we chose the fishery case above all to lend concreteness to the discussion. We hope that the basic conclusions of the model will be transferable to other CPR examples, such as groundwater-based irrigation, community grazing lands and village forests.

In the paper, we demonstrate that Olson's hypothesis — interpreted as a comparative-static statement that increasing inequality enhances efficiency — may not be always valid. In many settings increased inequality leads to less efficiency; this is true whether or not fishers have earning opportunities outside the commons. If these exit options are concave functions of wealth, increased inequality does not, in general, enhance the prospects for full conservation. Neither is it true that perfect equality always favors greater efficiency. At a certain wealth distribution, increasing wealth inequality increases equilibrium efficiency (though not attaining full conservation as long as both fishers have positive wealth), and furthermore, full conservation is an equilibrium under perfect *inequality*. In the model where fishers have exit options, full conservation cannot be an equilibrium under perfect equality if average wealth is below some threshold level.

The related assertion that the larger player has a greater interest in collective action than the smaller is borne out in many settings: with or without concave exit options, it is the poor who do not conserve. This too is dependent on the assumptions made: if exit option functions are convex, for example, it is the poorer fisher who has an interest in conditional conservation, while the richer fisher prefers the exit strategy. That the larger player, in many settings, has a greater interest in collective action than the smaller does not imply, however, that a more unequal distribution of wealth will lead to more successful collective action.

A significant result is that the relationship between inequality and collective action is not necessarily monotonic. In fact, the relationship may be U-shaped: at very low and very high levels of inequality, conservation is possible, while for some middle range of inequality it is not.

Although we focus on wealth inequality, in fact four types of inequality are analyzed: 1) asset inequality; 2) unequal exit options related to asset levels; 3) unequal exit options not related to asset levels; 4) unequal power to enforce agreements (by means of tax collection).

The outline of the paper is as follows. A basic noncooperative game is sketched. We extend the basic game to consider the effects on conservation if players have earning opportunities outside the commons. In general, the presence of exit options makes conservation less likely, but the results differ depending on the form of the exit-option function. Finally, we consider various schemes of community regulation of the commons in the light of the noncooperative model with or without exit

options.

The two-player model we use in this paper contributes to the tractability of the analysis and transparency of the results. A two-player model abstracts from the group-size problem highlighted by Olson (1965) in order to better focus on the problem of inequality. In Section 2.1, the results of the basic model are extended to the many-fisher case.

## 2 The fishery: A simple model

There are two fishers,  $i = 1, 2$ . Each is endowed with wealth  $e^i$  in each period. They share access to a common resource, namely a stock of fish  $F$ . In each of two periods  $t$ , each fisher must choose to spend some portion of his endowment on fishing capacity  $k_t^i$ ; thus,  $k_t^i \leq e^i$ . Each fisher's utility is simply the total amount of fish he catches:

$$U^i = \phi_1^i(k_1^i) + \phi_2^i(k_2^i)$$

where  $\phi_t^i(\cdot)$  is the amount of fish caught by fisher  $i$  in period  $t$ . Fishing yield is a function  $f$  of capacity deployed:  $f(k_t^i) = k_t^i$ , unless total capacity deployed exceeds the available fish, in which case each fisher gets a share of the total equal to his share of total wealth. (This is the situation known as “overcapitalization” in the literature on fisheries.) Each fisher's payoff in period 1, then, is given by

$$\phi_1^i(k_1^i) = \begin{cases} k_1^i, & k_1^1 + k_1^2 \leq F \\ \frac{k_1^i}{k_1^1 + k_1^2} F, & k_1^1 + k_1^2 > F \end{cases}$$

Between periods the stock of fish grows at rate  $g$ , so that in period 2 the supply of fish is  $G \cdot (F - \phi_1^1 - \phi_1^2)$ , where  $G \equiv 1 + g$ . In the second period, each fisher again chooses a capacity level. The nature of each fisher's endowment is such that any proportion of it can be used in each period for fishing. It is not spent. It reflects fishing “effort”, including number of boats and hours and intensity of labor. Note that in any efficient outcome there will be no fishing in period 1. We make the following “commons dilemma assumption”:

$$E \geq GF \tag{1}$$

where  $E \equiv e^1 + e^2$ . Assumption (1) ensures that the threat of resource degradation is sufficiently acute. Alternatively, (1) can be interpreted as a “feasibility” condition: the fishers are capable of harvesting the entire stock if they desire.

In the subgame which consists of the second period, both fishers will always fish to capacity. That

is, each will choose  $k_2^i = e^i$  and receive second-period payoff

$$\phi_2^i = \frac{e^i}{E}G(F - \phi_1^1 - \phi_1^2)$$

Thus we can concentrate on the fishers' actions in the first period. A strategy is just a capacity choice  $k_1^i$ , and the first-best outcome is  $k_1^1 = k_1^2 = 0$ . For simplicity, we will suppress the period subscript, since all strategic choices under consideration are made in period 1. (If  $g$  were negative there would be no real dilemma: first-period depletion of the resource would be an equilibrium and an optimum.) The crowding externality which is sometimes a feature of commons models does not occur in our model *within* periods;  $j$ 's action in period 1 does not enter  $i$ 's payoff in that period. However,  $j$ 's period-1 action will enter  $i$ 's period-2 payoff, and vice-versa.

The goal of conservation in fisheries is to reduce fishing to some level so that the remaining stock at the end of every period is sufficient to guarantee the survival of the fish population. In our simple model, that level has been normalized to zero in the first period. The second period extends to the end of the fishers' relevant economic horizons. The two-period set-up precludes consideration of complicated punishment strategies, but it is sufficient to capture the fundamental dilemma of resource conservation: namely, when is it reasonable to forego current-period consumption in return for higher next-period gains?<sup>6</sup>

In this model, we have abstracted from the problem of discount rates in order to focus more clearly on the incentives toward resource conservation. Formally, the discount rate would be subtracted from  $G$ , the rate of fish-stock regeneration. If the discount rate is greater than  $G$ , first-period depletion of the fishery is optimal, and conservation is not economically rational. Furthermore, it may be reasonable to suppose that each fisher's discount rate is a decreasing function of wealth. In this case, the more unequal the distribution endowments, the more difficult it will be to sustain universal conservation of the resource. It is as if the poor fisher faces a low rate of growth in the stock and hence has little incentive to conserve.

The following proposition notes the conditions under which the least efficient outcome is a Nash equilibrium.<sup>7</sup>

**PROPOSITION 1** *If  $e^i > F(G - 1)/G$  for  $i = 1, 2$ , then  $\{e^1, e^2\}$  is a Nash equilibrium.*

In particular, note that Proposition 1 implies that if  $e^i > F$  for  $i = 1, 2$  — if each fisher could unilaterally harvest the entire fish stock in the first period — then complete resource depletion is an

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<sup>6</sup>Other economic treatments of the fishery (Levhari and Mirman, 1980; Fudenberg and Tirole, 1991, pp. 510-513) have focused on changes in the incentives to conserve when the fish population varies; this can be approximated in our model by simply varying  $F$  as a comparative-static proposition.

<sup>7</sup>Proofs of the propositions in this paper are collected in the Appendix.

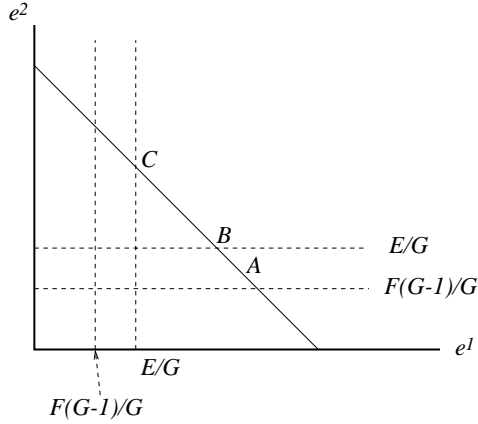


Figure 1: **Multiple Equilibria in the Simple Fishing Game**

equilibrium. When is full conservation a Nash equilibrium? The next proposition gives necessary and sufficient conditions.

**PROPOSITION 2** *In the basic game described above, when both players have positive wealth,  $k^1 = k^2 = 0$  is a Nash equilibrium if and only if  $e^i \geq E/G$  for  $i = 1, 2$ .*

The conditions of Propositions 1 and 2 may be satisfied simultaneously. In fact, whenever the condition in Proposition 2 is satisfied (i.e.,  $e^i \geq E/G, \forall i$ ), there are multiple equilibria, since the condition in Proposition 1 (i.e.,  $e^i \geq F(G-1)/G, \forall i$ ) will also be satisfied under assumption (1). This is illustrated in Figure 1.<sup>8</sup> The 45-degree line shows all possible distributions of wealth  $e^1 + e^2 = E$ . Both full conservation (Proposition 2) and full depletion (Proposition 1) are equilibria for the range of wealth distributions  $BC$ . At a point such as  $A$ , full conservation is not an equilibrium; after an equalizing redistribution of wealth to a point between  $B$  and  $C$ , full conservation would be an equilibrium.

Intuitively,  $E/G$  is the threshold amount of wealth above which the fisher will conserve, conditional on his counterpart's conservation. Alternatively, the condition  $e^i \geq E/G$  for  $i = 1, 2$  can be interpreted as defining a minimal regeneration rate  $g$  such that mutual conservation is possible in equilibrium. For the two-fisher case we are considering here, this condition is equivalent to  $G \geq 2$ . This means that the fish stock must grow at a rate of 100%. This may seem worrisomely high; moreover, the astute reader will have noticed that the  $n$ -player version of Proposition 2 will imply that conservation requires that  $G$  be greater than  $n$ . This result is quite robust. For any general fishing technology  $f(k^i)$  and sharing rule  $(\{\alpha_i\}_{i \in I}, \sum \alpha_i = 1)$  in the case of overcapitalization, it

<sup>8</sup>This figure was suggested by Timothy Besley.



can be shown that the appropriate generalization of Proposition 2 implies that  $G \geq n$ , where  $n$  is the number of players in the set  $I$ . This is not necessarily the case if the share  $\alpha_i$  accruing to fisher  $i$  is a function of first-period conservation, as it might be in the case of a regulated fishery. We will return to this point in Section 4.3.

This proposition suggests the following corollary. Define  $\Delta(E) \equiv \{(e^1, e^2) | e^1 \geq 0, e^2 \geq 0, e^1 + e^2 = E\}$  as the set of all distributions of  $E$ . For any  $e = (e^1, e^2) \in \Delta(E)$ ,  $\hat{e} \in \Delta(E)$  is a *mean-preserving spread* of  $e$  if  $|\hat{e}^1 - \hat{e}^2| > |e^1 - e^2|$ .

**COROLLARY** (a) Consider  $e, e' \in \Delta(E)$ , where  $e'$  is a mean-preserving spread of  $e$ . Then  $k^1 = k^2 = 0$  is an equilibrium with  $e'$  only if it is an equilibrium with  $e$ . (b) For all  $e \in \Delta(E)$  there is a mean-preserving spread  $e'$  such that  $k^1 = k^2 = 0$  is not an equilibrium with  $e'$ .

The Olson hypothesis that inequality enhances the prospects for collective action can be interpreted as a comparative-static statement: namely, that increasing inequality (for a given level of aggregate wealth) makes full conservation more likely. The corollary above suggests that this is not so. Part (b) states that, starting from any wealth distribution, there exists a less equal wealth distribution such that full conservation is not an equilibrium. In particular, if full conservation is an equilibrium under the initial distribution, then we know from Proposition 2 that  $e^i \geq E/G$  for  $i = 1, 2$ . Then wealth can be taken from one fisher until  $e^i < E/G$  for that fisher; full conservation is no longer an equilibrium. In terms of Figure 1, this is equivalent to moving from a point in the region  $BC$  to a point such as  $A$ .

The corollary to Proposition 2 illustrates that increased inequality does not necessarily lead to equilibrium conservation. Proposition 3, however, shows that under maximum inequality – that is, when one fisher holds all of the wealth – conservation is an equilibrium.

**PROPOSITION 3** *In the basic game, if  $G$  is greater than or equal to one, then under perfect inequality ( $e = (E, 0)$  or  $e = (0, E)$ ), full conservation is a Nash equilibrium.*

In part, Proposition 3 reflects Olson’s hypothesis that cooperation is more difficult in a group the larger the number of group members. In our fishery, conservation is an equilibrium outcome when the number of fishers with positive wealth is reduced to one.

The propositions above consider only the conditions under which full conservation by both fishers is an equilibrium. The more realistic case in an unregulated fishery, and the case which may be closer to Olson’s thinking, is the one in which changes in the distribution of wealth change the level of efficiency among a set of *inefficient* equilibria. This is considered in following proposition. Proposition 4 says that if the distribution of wealth is sufficiently unequal already, then making

it even more unequal can increase efficiency. Define  $M(e)$  as the minimum amount of first-period fishing among all Nash equilibria of the game when the distribution of endowments is  $e$ .

**PROPOSITION 4** *For all  $E$  such that  $E > GF$ , there exists  $\hat{e} \in \Delta(E)$  such that for all mean-preserving spreads  $e'$  of  $\hat{e}$ ,  $M(e') < M(\hat{e})$ .*

Proposition 4 demonstrates that for the wealth distribution  $\hat{e}$ , where

$$\hat{e} \equiv (E - \frac{G-1}{G}F, \frac{G-1}{G}F)$$

and all mean-preserving spreads of  $\hat{e}$ , fisher 1 will conserve regardless of the other's behavior.<sup>9</sup> The Proposition also illustrates that the full-conservation equilibrium under perfect inequality in Proposition 3 is a limiting case as inequality is increased. For distributions such as  $\hat{e}$ , one fisher captures a sufficiently large share of the returns to conservation that he will unilaterally conserve. In particular, there exists an equilibrium in which the larger fisher conserves, the smaller fisher does not, and any mean-preserving spread increases efficiency. If it were true that  $i$ 's endowment were greater than  $E/G$ , then by Proposition 2, fisher  $i$  would always conserve if fisher  $j$  did. But since  $E > (G-1)F$  (which is guaranteed by condition (1)), then  $e^i < E/G$ , and full-capacity period-1 fishing is a best reply by fisher  $i$  to full conservation by fisher  $j$ . Thus any mean-preserving spreads of  $\hat{e}$ , by reducing fisher  $i$ 's capacity, will increase efficiency, since fisher  $j$  will play 0 and more fishing will be deferred until the second period.<sup>10</sup> This, then, is the commons analog of the Olson public-goods hypothesis.

This situation is summarized in Figure 2, which shows (assuming  $G \geq 2$ ) that as fisher  $i$ 's wealth share increases from  $\frac{1}{2}$ , full efficiency is maintained until his share reaches  $(G-1)/G$ , at which point the other fisher defects, reducing total catch. Then as the share of  $i$  continues to increase, the efficiency of the system increases apace, since the other fisher is capable of harvesting a decreasing fraction of the fish stock in period 1. When  $i$  owns all the wealth, full efficiency is restored.<sup>11</sup>

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<sup>9</sup>If we restrict the parameters so that  $E = FG$ , then, for  $G = 2$ , the wealth distribution  $\hat{e}$  is given by  $(\frac{3}{4}E, \frac{1}{4}E)$ . As  $G$  is increased beyond 2,  $\hat{e}$  becomes less equal.

<sup>10</sup>Thus Olson (1965, p. 35) writes: "This suboptimality or inefficiency will be somewhat less serious in groups composed of members of greatly different size or interest in the collective good. In such unequal groups, on the other hand, there is a tendency toward an arbitrary sharing of the burden of providing the collective good...[T]here is accordingly a *surprising tendency for the 'exploitation' of the great by the small.*"

<sup>11</sup>This figure was suggested by Jean-Marie Baland.

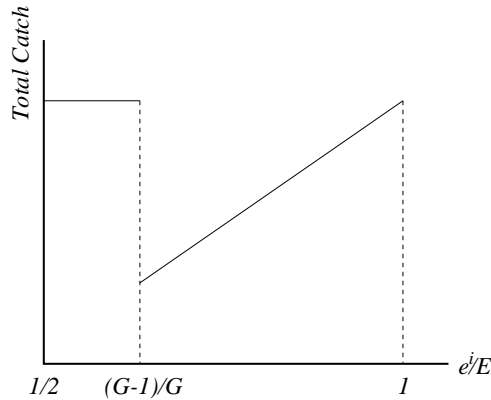


Figure 2: **Inequality and the Efficiency of Cooperation**

## 2.1 More than two fishers

Most of our results are not qualitatively changed if there are more than two fishers. Proposition 5 extends both our Propositions 2 and 4. In what follows, we call any outcome in which some fishers fully conserve until the second period “partial conservation.” Note that we do not mean that some fishers partially conserve. Say that there is a set of fishers  $I$ . Although it will not be necessary in the proof of the proposition, let us say that if some subset of fishers  $\hat{I} \subset I$  fishes to capacity in period 1, and they deplete the fish stock, then each of these “defecting” fishers  $i$  receives

$$\frac{e^i}{\sum_{i \in \hat{I}} e^i} F$$

**PROPOSITION 5** *In the basic game with more than two fishers, in which all fishers have positive wealth, partial conservation is an equilibrium if and only if:*

1. *for all fishers  $i$  in the subset  $\hat{I} \subset I$  of fishers who do not conserve,  $e^i < E/G$ ;*
2. *for all fishers  $i$  in  $I \setminus \hat{I}$ ,  $e^i \geq E/G$ ; and*
3.  $\sum_{i \in \hat{I}} e^i < F$ .

**COROLLARY** *Suppose that partial conservation is an equilibrium outcome. (a) If there is a fisher  $l$  in  $I \setminus \hat{I}$  such that  $e^l > E/G$  and another fisher  $m$  in  $I \setminus \hat{I}$  such that  $e^m > e^l$ , then there exists a mean-preserving spread of the initial wealth distribution under which partial conservation is still an equilibrium. (b) There exist efficiency-enhancing mean-preserving spreads of the initial wealth-distribution.*

Part (a) merely states that mean-preserving spreads of the wealth distribution do not necessarily destroy a cooperative equilibrium outcome: take some wealth from  $l$  (but make sure that  $e^l$  is still greater than or equal to  $E/G$ ) and give it to  $m$ . Part (b) goes further and states that mean-preserving spreads may enhance efficiency in the spirit of Proposition 4 (in the two-fisher case): take some wealth from  $p \in \hat{I}$  and transfer it to some  $q$  in  $I \setminus \hat{I}$  (who is by definition wealthier). Then there is no change in the composition of  $\hat{I}$ , but the amount of first-period fishing is reduced by exactly the amount of wealth taken from  $p$ .

Finally, if partial conservation is an equilibrium outcome, there may exist wealth-equalizing transfers such that full depletion is the only equilibrium under the new wealth distribution. Suppose that  $\hat{I}$  is such that  $\sum_{i \in \hat{I}} e^i = F - \epsilon$  for  $\epsilon > 0$  small. Then we take wealth

$$\frac{E}{G} - e^r + \epsilon$$

from some fisher  $r \in I \setminus \hat{I}$  and transfer it to some (poorer) fisher  $s \in \hat{I}$ . Now  $r$  will fish to capacity in period 1, but so will all the other fishers, since condition 3 of the proposition is no longer satisfied, and partial conservation is not an equilibrium.

Now it remains to generalize to the  $n$ -fisher case Proposition 4, which states that once the wealth distribution is sufficiently unequal, further mean-preserving spreads of that distribution increase equilibrium efficiency. The proof of Proposition 4 constructs this threshold wealth inequality. Proposition 6 below gives sufficient conditions on the wealth distribution such that increases in inequality (weakly) increase equilibrium efficiency in the  $n$ -fisher extension of the basic game; part of the task of Proposition 6 is to characterize what is meant by “sufficiently unequal” in the many-fisher case.

Let us restrict attention to a particular class of mean-preserving spreads of the wealth distribution. Consider bilateral wealth transfers from a fisher  $j$  to a fisher  $k$  such that  $e^j < E/G$  would fish to capacity in period 1 before the transfer, and  $e^j \leq e^k$ . Call this class of mean-preserving spreads *unequalizing wealth transfers*. Many more complicated mean-preserving spreads can be characterized as the outcome of a sequence of such unequalizing wealth transfers.

**PROPOSITION 6** *In the  $n$ -fisher extension of the basic fishing game, define  $\tilde{I} \equiv \{i \in I | e^i \geq E - F \frac{G-1}{G}\}$ , and define  $J \equiv \{i \in I | e^i < E/G\}$ . If  $\tilde{I}$  and  $J$  are nonempty, then after any unequalizing wealth transfer first-period fishing is weakly lower.*

Proposition 6 states that if there is at least one fisher whose wealth is below the conservation threshold  $E/G$ , and at least one fisher whose wealth is sufficiently large that he will conserve regardless of the actions of the other fishers, then there always exist wealth redistributions that increase inequality and (at least weakly) equilibrium efficiency.

Note that the conditions of Proposition 6 are not met if all fishers conserve initially (i.e.,  $J$  is empty). From Proposition 5, we know that this situation can only hold if all fishers have wealth at least as great as  $E/G$ . Thus in that situation, the wealth distribution is not sufficiently unequal for the Olson-style mechanism of Propositions 4 and 6 to operate.

### 3 Exit options

In fisheries worldwide, large fishing companies with more opportunities to move their fleets elsewhere (compared to the small-scale local fishers) are much less concerned about conservation of fish resources in a given harvesting ground. This has been noted in the case of the Texas shrimp fishery by Johnson and Libecap (1982): there, larger fishers have defected from quota schemes. Baland and Platteau (1996) have noted similar phenomena in a Japanese fishery, where industrial seiners are more apt to deplete fish stocks than local artisanal hook-and-line fishers.

The phenomenon extends to other CPRs. In Mali and Mauritania large (usually absentee) livestock herd owners have been much less interested than small herders in local arrangements for rangeland management to prevent overgrazing and desertification (Shanmugaranam *al.*, 1992, cited in Baland and Platteau, 1996). Freudenberger (1991) describes the deforestation of a forest ecosystem in Senegal by the local unit of a nationwide Muslim agricultural entity (the Mouride). A relatively low-intensity pattern of resource use by nearby peasant producers and pastoralists gave way to intensive cash-crop (groundnut) production. After the soil's rapid exhaustion by groundnut farming, the Mouride's national decision-making body could open up new territory elsewhere, unlike traditional users who were more interested in the long-term viability of the local forest. (Ostrom repeatedly stresses the importance of dilemmas like the Mouride case as examples of "heterogeneous discount rates", a form of inequality. If indeed agents have different discount rates, the difference can be explained in terms of deeper parameters, such as different exit possibilities (easily derived from asset inequalities), or other similar factors (e.g., different access to credit).

In all of the cases cited above, the richer or larger commons users were prone to defect. This need not always be the case. Other authors have reported that the poorer or smaller users may exercise an exit option. Bergeret and Ribot (1990), in a study similar to that of Freudenberger, describe deforestation in a larger area and over a longer time frame, also in the Senegalese Sahel. Trees are overharvested by Fulani refugees from Guinea, who are more likely to be landless than other peasants, in order to produce charcoal for the rapidly growing urban market. A qualitatively similar situation has been described in southern Burkina Faso, where immigrants are more prone to use

destructive gathering techniques in communal forests (Laurent *et al.*, 1994, cited in Baland and Platteau, 1997).

### 3.1 Concave exit options

Let us then augment the basic game presented above so that each fisher has an option to exit rather than fish in the second period. If only one fisher exits in the second period, the other receives the entire second-period catch. Let the value of each fisher  $i$ 's exit option be given by the function  $\psi(e^i)$ . This makes the plausible assumption that the exit option may depend on a fisher's endowment level: "exit" may refer to investing or deploying one's capacity in another sector. In general, the *value* of each fisher's exit option will not be the same, unless they have equal endowments. Note that this does not rule out the case that  $\psi(\cdot)$  is a constant. It does for the time being rule out the possibility that each fisher has a different exit option *function*: that is, we assume that if  $e^i = e^j$ , then the fishers' exit options are the same.

When is full conservation an equilibrium in this new setting? For a given fisher  $i$ , conditional on fisher  $j$ 's conservation (that is,  $j$ 's first-period catch is zero), it must be that  $i$ 's share of the second-period catch is greater than the value of deviating (fishing to full capacity in period 1 and exiting in period 2). That is, for  $i = 1, 2$ ,

$$\frac{e^i}{E}GF \geq \min(e^i, F) + \psi(e^i) \quad (2)$$

In general, any comparative-static assertions about whether full conservation will be a Nash equilibrium under different wealth distributions will depend on the nature of the  $\psi(\cdot)$  function.

Thus we will impose the restriction that  $\psi(\cdot)$  is a concave function, and furthermore that

$$\psi'(e^i) \geq 0 \quad (3)$$

In addition, we will restrict attention to cases where "distribution matters"; that is, cases where there exists some distribution such that full conservation is *not* an equilibrium. This can be stated as follows: there exists some  $e^*$ ,  $0 < e^* \leq E$ , at which

$$\frac{e^*}{E}GF = \min(e^*, F) + \psi(e^*) \quad (4)$$

If assumption (4) is not satisfied, then either full conservation or exit is preferred by both fishers at all levels of wealth, conditional on the conservation of the other. Moreover, for simplicity, we shall assume that

$$\psi(0) = 0 \quad (5)$$

Finally, we wish to restrict attention to the case where the fishery is economically viable, in the sense that the maximum possible fish production in the second period is greater than fishing to capacity in the first period and exiting with all of the fishery's capacity in the second period. That is,  $GF \geq F + \psi(E)$ . This can be restated as:

$$\psi(E) \leq (G - 1)F \quad (6)$$

In what follows, let the *exit strategy* be the following course of action by one of the fishers: fish to capacity in period 1, and exit in period 2. Now we can state the following propositions. We emphasize that these are comparative-static results, not statements about the effect of redistribution.

**PROPOSITION 7** *Consider the augmented game in which each fisher  $i$  has a second-period exit option described by the function  $\psi(e^i)$ .  $\psi(\cdot)$ ,  $G$ ,  $F$ , and  $E$  satisfy assumptions (3), (4) and (5). Then, given any wealth distribution  $e \in \Delta(E)$  which gives each fisher positive wealth, there exists a mean-preserving spread  $e'$  of  $e$  such that full conservation is not an equilibrium under  $e'$ .*

Proposition 7 suggests the following corollary, which addresses the Olson hypothesis in the context of concave exit options.

**COROLLARY** *If under perfect equality of wealth full conservation is a Nash equilibrium, then there exists a mean-preserving spread  $e'$  such that full conservation is not an equilibrium.*

This corollary says that when the exit option is a nondecreasing concave function, together with the restrictions implied by assumptions (4) and (5), then whenever full conservation is an equilibrium with a perfectly equal distribution of wealth, there always exists a less equal distribution of wealth such that full conservation is not an equilibrium. In this case, equality is more conducive to conservation. Note that under the unequal distribution of wealth, it is the poorer agent who finds it in his interest to play the exit strategy. As we will see in a later section, this result generalizes to the case where only one fisher has an exit option.

The principal issues raised in Proposition 7 and its corollary can be depicted graphically. First note that the Nash-equilibrium condition (2) can be rewritten as

$$\psi(e^i) \leq \frac{e^i}{E}GF - \min(e^i, F) \quad (7)$$

In Figure 3, fisher  $i$ 's wealth is given on the horizontal axis, and  $i$ 's payoff is given on the vertical axis. The right-hand side of (7) is drawn as  $ONM$ , and the left-hand side ( $\psi(\cdot)$ ) is given by the concave function  $OS$  ( $\psi(e^i) = \sqrt{e^i}$ ). Note that the sign of the right-hand side of (7) determines whether full conservation is an equilibrium in the basic (no-exit-option) game. From Proposition 2, then, we know that the right-hand side must be positive for all values of  $e^i$  greater than  $E/G$ , which

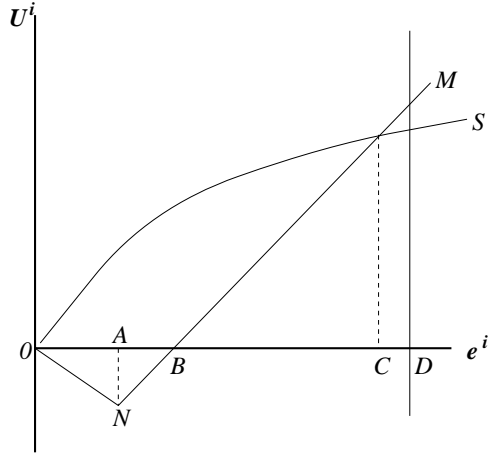


Figure 3: **A Concave Exit-Option Function**

is labeled as point  $B$  in Figure 3. The point labeled  $A$  corresponds to  $F$ , the initial fishing stock.  $A$  is the point of intersection between the lines  $U^i = e^i(\frac{GF}{E} - 1)$  to the left (note that the slope is negative as a result of the “commons dilemma” assumption (1)) and  $U^i = e^i\frac{GF}{E} - F$  to the right. The wealth level  $e^*$  is labeled as point  $C$ . At all wealth levels to the right of  $C$ , fisher  $i$  strictly prefers conservation, conditional on conservation by fisher  $j$ ; at all wealth levels to the left of  $C$  (but not including the origin), fisher  $i$  prefers the exit strategy.

In Figure 3 and all subsequent figures,  $E$  is treated as a constant. That is, as  $e^i$  is increased,  $E$  does not increase; it is assumed that  $e^j$  is decreased by an equal amount. Alternatively, the horizontal axis of the figures may be interpreted as representing the *share* of total wealth held by a particular player in the case where  $E$  is equal to one.

According to the corollary to Proposition 7, if full conservation is an equilibrium in a situation of perfect equality, then there is a mean-preserving spread of the wealth distribution under which full conservation is not an equilibrium. Suppose that the two fishers are initially endowed with wealth level  $D$  in Figure 3. Then by redistributing wealth away from fisher 1 until his wealth lies to the left of point  $C$ , full conservation is no longer an equilibrium; at such a new distribution,  $0S$  lies above  $0NM$  for fisher 1, and he will prefer the exit strategy.

Figures 4 and 5 depict the same situation for different forms of the exit option function. In both figures, the exit options are weakly concave.

In Figure 4, the exit option function takes the form  $\psi(e^i) = be^i$  for nonnegative  $b$ . It may be, for example, that  $b$  is an interest rate that can be earned if a fisher’s capacity is invested elsewhere.



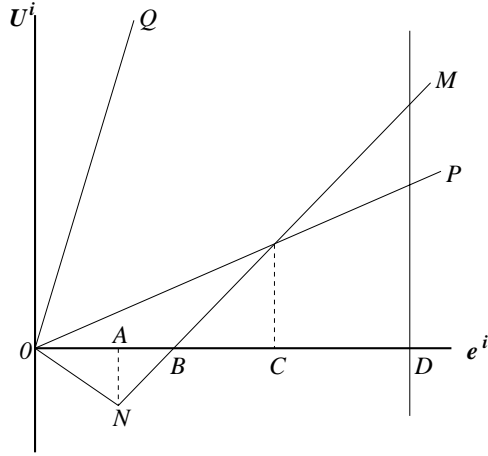


Figure 4: **A Linear Exit-Option Function**

Functions for two values of  $b$  are shown. The line  $\theta Q$  represents a value of  $b$  so high that neither fisher would ever conserve; this is ruled out by our assumption (4). The line  $\theta P$  represents a lower value of  $b$  and can be analyzed like Figure 3 (all of the analogous points are labeled with the same letters).

Figure 5 depicts an exit option function of the form

$$\psi(e^i) = \begin{cases} 0, & e^i = 0 \\ a, & e^i > 0 \end{cases}$$

for some  $a > 0$ . It can be analyzed in the same way as Figures 3 and 4. This type of exit option corresponds to a fixed lump-sum which is available to each fisher in the second period, and is invariant to their levels of wealth.

Proposition 8 illustrates that the conclusion of Proposition 7 is not completely general; that is, in the vein of Olson, *extreme* inequality may *enhance* the prospects for conservation.

**PROPOSITION 8** *In the augmented exit-option game when assumptions (3) through (6) hold, under perfect inequality ( $e = (E, 0)$  or  $e = (0, E)$ ), full conservation is an equilibrium.*

Proposition 8 immediately suggests the following corollary.

**COROLLARY** *For any given distribution of wealth  $e$  such that  $e^i > 0$  for  $i = 1, 2$ , there always exists a mean-preserving spread of  $e$  such that full conservation is an equilibrium.*

Proposition 8 illustrates that the logic of Olson's inequality hypothesis extends to the case of the concave exit option. Proposition 7 illustrates, however, that with concave exit options, Olson's

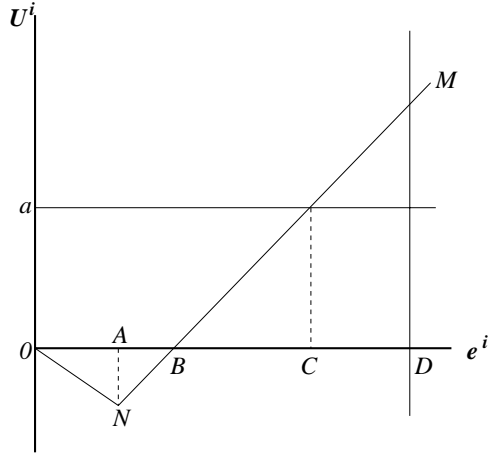


Figure 5: **A Constant Exit-Option Function**

hypothesis cannot be interpreted as a general comparative-static result. Finally, Proposition 9 below indicates that there are cases when the conditions underlying Proposition 7 do not hold: that is, there is no full-conservation equilibrium with perfect equality.

**PROPOSITION 9** *Consider the augmented game described in Proposition 7, where assumptions (3) through (6) hold. If average wealth is less than  $e^*$ , then under perfect equality, full conservation is not a Nash equilibrium.*

Refer to Figures 3 through 5. Proposition 9 states that if average wealth lies to the left of point  $C$ , then under perfect equality, both fishers would prefer the exit strategy, and full conservation will not be an equilibrium.

As we will see in a later section, this result generalizes to the case where only one fisher has an exit option. Note that the condition in Proposition 9 that average wealth is less than  $e^*$  does not contradict assumption (6). Assumption (6) requires only that total wealth is greater than  $e^*$ . Proposition 9 suggests that whether or not average wealth is less than  $e^*$  is an important criterion for whether a given commons situation (with concave exit options) is subject to “Olson effects”. Specifically, if average wealth is less than  $e^*$ , then increased inequality is necessary for equilibrium conservation.

### 3.2 Convex and asymmetric exit options

In the cases analyzed in Propositions 7 through 9 and illustrated in Figures 3 through 5, the return to the exit strategy, relative to conservation (and always conditional on conservation by the other

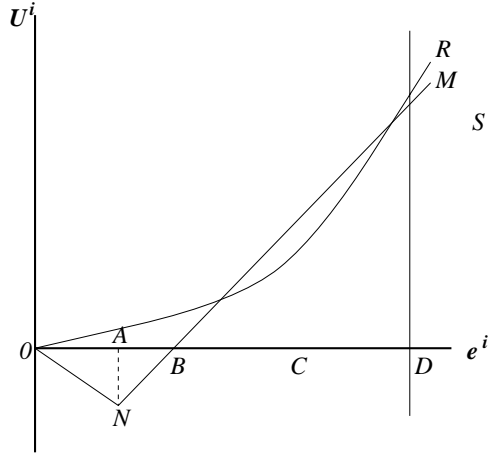


Figure 6: **A Convex Exit-Option Function**

fisher) is diminishing in wealth. In case studies of commons with exit options it is frequently (though by no means exclusively) asserted that, when exit occurs, it is the large resource users who exit. In Proposition 7, as we have noted above, when there is exit, it is the smaller fisher who exits. How is this reconciled with the empirical evidence of exit by the large? First, it may be that exit options are not concave (or even weakly concave) functions of wealth. Second, it may be that the exit option *functions* (and not just the exit option *values*) are different for the different fishers. Each of these possibilities is considered in turn.

### 3.2.1 Convex exit option functions

Figure 6 illustrates a convex exit-option function. The principal complication is that there are several “crossover” points, points which correspond to  $e^*$  in the concave case. Thus, for example, begin at a position of perfect *inequality* with total wealth  $D$  in Figure 6 (that is, one fisher’s endowment is  $D$ , and the other’s is zero). Full conservation is not an equilibrium, because the fisher with positive wealth will prefer the exit strategy. If wealth is more equally redistributed in the range of point  $C$ , full conservation is an equilibrium. However, if one fisher’s wealth is  $C$  while the other’s is in the range of  $A$ , full conservation is not an equilibrium.

Situations such as those depicted in Figure 6 may well describe many commons with exit options. In general, because of the kinked “convex” shape of the right-hand side of (7), a convex left-hand side of (7) will cross the right-hand side more than once. With convex exit option functions, we can make the following proposition, which does not, in general, hold when exit option functions are

concave.

**PROPOSITION 10** *Consider the augmentation of the basic game, in which each player has an exit option given by  $\psi(e^i)$ .  $\psi(\cdot)$  is a convex function of wealth, and  $\psi(0) = 0$ . If there exists any  $e \in \Delta(E)$  such that both fishers have positive wealth, under which full conservation is an equilibrium, then full conservation is an equilibrium under perfect equality.*

### 3.2.2 Asymmetric exit options

In some commons situations, players' exit options are qualitatively different. Thus it may be, for example, that in a particular in-shore fishery, it is not simply that the poorer fisher has less capacity, but instead a fundamentally different fishing technology than the larger fisher. The larger fisher can move his ocean-going trawler to another harvesting ground, but if the poorer fisher tried to do the same in his small primitive boat, he would stand a good chance of dying at sea. More generally, it may be that the smaller player's capacity is location-specific in a way that the larger player's is not.

Suppose that only one fisher has an exit option: this seems a not-too-extreme approximation of the asymmetric-technology argument made in the previous paragraph. Figure 3 can be reinterpreted to depict this case. Suppose that  $OS$  is fisher 1's exit option function, and that  $ONM$  is the conditional payoff to conservation for both fishers. Conditional on fisher 1's conservation, fisher 2 will conserve anywhere to the right of point  $B$ . Here the problem is not that fisher 2 will exit, but rather that he will deviate from conservation by fishing to capacity in period 1. Now if the fishers were to begin at a position of perfect equality at  $D$ , full conservation would be an equilibrium. If fisher 2's wealth were reduced to some amount between  $B$  and  $C$  (and fisher 1's wealth correspondingly increased), full conservation would still be an equilibrium, unlike the case of Proposition 7. Nevertheless, if fisher 2's wealth were reduced to a point between 0 and  $B$ , he would choose to deviate, and full conservation would not be an equilibrium. If fisher 2's wealth were reduced to 0, then as in Proposition 8, full conservation is an equilibrium. Finally, if average wealth lies to the left of  $C$ , then as in Proposition 9, there is no full-conservation equilibrium under perfect equality.

In the asymmetric exit option case, our previous interpretation of mean-preserving spreads changes in two ways: first, whether or not a mean-preserving spread destroys a full-conservation equilibrium depends on the identity of the fisher who gains under the redistribution; second, the minimum unequalizing redistribution needed to destroy a full-conservation equilibrium must be *more* unequalizing than the minimum necessary redistribution in Proposition 7.

Throughout Section 3, our assumption that exit options are at least weakly concave makes strong

comparative-static results possible. In the diagrams above, the concavity assumption leads to a sort of “single-crossing” property: there exists a range of wealth levels at which a fisher will not conserve conditional on the other’s conservation, and at all higher wealth levels, the fisher will conditionally conserve. Nevertheless, if there is more than one crossing of the two curves in the diagrams — as in the case of the convex exit option function — then the comparison of two or more wealth distributions is more complex. If in the case where there are multiple crossings conservation is not initially an equilibrium, it is not always possible to say whether or not it will be an equilibrium under any more (or less) unequal distribution. If the right-hand side of the inequality (7) is also concave (which might occur under considerably more complicated assumptions about the fishing production function), then even with concave exit option functions this may give rise to multiple crossings.<sup>12</sup>

The nature of the exit option functions is ultimately an empirical question. In many situations, exit option functions could plausibly be linear beyond some level of wealth — this represents a risk-free bond earning a fixed interest rate. But at lower levels of wealth, the exit option function may be convex as a result of borrowing constraints. Nevertheless, the presence of exit options, whatever their form, generally complicates the prospects for conservation.

## 4 Crafting distributive rules

The noncooperative model sketched in sections 2 and 3 of this paper sheds some light on the complicated relationship between inequality and cooperation in an unregulated commons situation. One of the themes emphasized by many writers in the current policy discussion of the commons is that such problems are best described not always as prisoners dilemmas, but rather that in many cases they may be problems of coordinating among multiple equilibria (Runge, 1981; Ostrom, 1990, pp. 46-47). As pointed out in section 2, this feature is exhibited by our model: when the conditions of Proposition 2 are satisfied (i.e.,  $e^i \geq E/G$  for  $i = 1, 2$ ), both resource degradation (depletion of the fish stock in period 1) and full conservation (no fishing in period 1) are equilibria. However, under many parameter configurations, we have also seen that the problem is indeed a prisoners dilemma: full conservation, though a Pareto optimum, is not an equilibrium.

One might correctly presume that in real-world commons problems, economic actors may craft institutions to regulate community use of common-pool resources. Indeed, the comparative experiences

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<sup>12</sup>Consistent with Bénabou’s (1996) discussion of “inequality of income versus inequality of power,” what matters is not inequality of wealth *per se*, but inequality of wealth relative to exit options. If the value of one fisher’s exit option grows faster than one-for-one with his wealth, then wealth inequality will foster rather than hinder cooperation.

of resource users in crafting such rule-complexes is a predominant theme in contemporary commons studies. Ostrom (1990) is the most notable example of this. Feeny, Hanna, and McEvoy (1996) base their attack on the “Tragedy of the Commons” interpretation of fisheries on the prevalence of local regulatory schemes. If the problem is one of multiple equilibria, presumably the task of such self-regulation is merely to coordinate actors on one Pareto-efficient equilibrium. If the problem is a prisoners dilemma, however, there must be a structure of rules, very likely with monitoring and enforcement, which transforms the dilemma into a coordination game and the Pareto superior outcome into a self-enforcing equilibrium.

Fishers worldwide have elaborated schemes of social regulation with varying degrees of success. An ingenious example is the Alanya fishery in Turkey, where fishers are randomly assigned initial individual fishing sites; every day each fisher moves over one site (Berkes, 1986). On the Bahia coast of Brazil, fishers are likewise assigned to sites. Here social pressures exist which compel especially successful fishers to share — either fish or wealth — with others in the community (Cordell and McKean, 1986). In the Solomon Islands, fishers are prevented from encroaching on the sites of others by the threat of expulsion from the community by the local chieftain (Hviding and Baines, 1994). In some Philippine fisheries, the daily catch is divided equally among the fishers regardless of the quantity each individual catches (Lopez, 1984, cited in Baland and Platteau (1997)).

Many authors have asserted that attempts to craft rules to regulate resource use are hampered by the unfeasibility of certain mechanisms (Johnson and Libecap, 1982; Kanbur, 1991; Baland and Platteau, 1996). In this section we will consider various possible mechanisms in isolation. In particular, we do not propose a formal theory of rule-crafting; rather we discuss various types of regulatory schemes that could conceivably be adopted, in the light of the noncooperative results in sections 2 and 3.

What are the possible regulatory mechanisms that might be used to regulate our fishery? We will consider three: fishers may redistribute wealth before the game is played; they may redistribute fish after the first period; or they may redistribute fish after the second period. In each case, we are interested in knowing whether a first-best outcome can be realized, particularly in cases where a first-best is not an equilibrium outcome of the unregulated game. (A “first-best” is any outcome in which there is no fishing in period 1, and capacity fishing in period 2.)

The self-regulatory schemes we consider have two possible effects on the payoff structure of the game. First, there may be some fine imposed on a player who does not abide by the cooperative agreement: this reduces the return to cheating. Second, there may be some sharing of output in the cooperative outcome which is different than the default sharing rule in the noncooperative game (i.e.,  $\{e^i/E\}_{i \in I}$ ). This change in the sharing rule may arise from the redistribution of output after

the game, or from a pre-play wealth redistribution.

#### 4.1 Redistribution of capacity

Propositions 1 through 4 and their corollaries regarding the basic model, are comparative-static results considering the effect on efficiency of changes in the wealth distribution. If we make the assumption that wealth can be redistributed, these results can be re-interpreted as statements about the effects of redistribution.<sup>13</sup> Thus, Proposition 2 tells us that, for asset distributions which give each fisher positive wealth, full conservation is an equilibrium if and only if each fisher's share of total wealth is greater than  $1/G$ . If  $G$  is at least two, then there always exists a wealth transfer (perhaps negative) from fisher 1 to fisher 2 such that full conservation is an equilibrium outcome. With the appropriate wealth transfer, full conservation can be supported as an equilibrium, even if it was impossible under the initial distribution. However, one may ask whether both fishers (in particular, the fisher who is asked to give up some wealth) would agree to such a transfer: in a fairly loose sense, is this scheme of social regulation "incentive-compatible"?

Let us say that the fisher who must cede some wealth to the other is fisher 2. If the fishers do not agree to transfer  $s$  between them, presumably the bad equilibrium will be played. In that case, fisher 2's payoff is  $e^2 F/E$ . If the transfer is effected and the good equilibrium results, fisher 2's payoff is  $(e^2 - s)GF/E$ . Is the latter greater than the former? It is, as long as

$$s \leq e^2 \left( \frac{G-1}{G} \right) \tag{8}$$

As long as the condition in Proposition 2 is satisfied for fisher 2 post-transfer, then (8) is satisfied as well. This result extends to the case where the fishers have concave exit option functions.

When  $G \geq 2$ , and if  $e^* > E/2$  in the case where fishers have concave exit option functions, the nature of the distributive rule is that the richer fisher transfers wealth to the poorer in order to ensure conservation. That is, the richer fisher must pay off the poorer; without such a transfer, the poor fisher will defect.

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<sup>13</sup>Many of the rule-complexes described in the field-study literature and mentioned above reallocate fishing locations: these can be interpreted as a redistribution of capacity. If fishing locations have different productivities, the default share of the fishing stock accruing to each player will be different. Note that for our model to apply, it must also be the case that the fishing locations are not isolated from one another.

## 4.2 Taxes

Now let us suppose that fishers can effect transfers (of fish) conditional on the size of their individual first-period catches. Effectively, this means that they can tax each other's first-period catch. If period-1 catch can be taxed at a rate of 100 percent, then a first-best can be implemented under just about any circumstances (including most exit-option scenarios). This is essentially the same thing as "boat licensing" in our model: limiting the number of boats (i.e., the proportion of  $e^i$ ) that fisher  $i$  uses in period 1 is directly related to limiting his catch.

### 4.2.1 Asymmetric enforcement

A more interesting possibility is that only one fisher can be taxed, a situation that we call *asymmetric enforcement*. It is plausible to assume that some factor (economic or otherwise) makes it possible for one fisher to impose a sanction on the other, but that the latter is impeded from reciprocating. More concretely, we assume in this section that one fisher can confiscate the other's first-period catch, if positive. It is also plausible that this power to enforce is correlated with wealth, a possibility we will consider.

Suppose that fisher 1 can collect the 100 percent tax from fisher 2, but fisher 2 cannot tax fisher 1. First, this makes fisher 2 prefer conservation at any level of his wealth, conditional on fisher 1's conservation. Fisher 1 will conserve, conditional on fisher 2's conservation, if he is at least as well off as if he were to deviate and fish to capacity in period 1:

$$\frac{e^1}{E}GF \geq \min(e^1, F)$$

The following proposition, as in the previous section, considers an unregulated setting in which conservation is not an equilibrium. In this case we explore whether conservation may emerge as an equilibrium with the introduction of asymmetric enforcement.

**PROPOSITION 11** *Suppose that for a given  $E$ ,  $e \in \Delta(E)$ ,  $F$  and  $G$ , full conservation is not an equilibrium, and that for some fisher  $i$ ,  $e^i > E/G$ . Suppose that the game is modified so that one and only one fisher  $t$  can tax the other's first-period catch at a rate of 100 percent. (a) If  $i = t$ , then full conservation is now a Nash equilibrium. (b) If  $i \neq t$ , full conservation is not an equilibrium.*

If the condition  $e^i > E/G$  is not true for *either* fisher  $i$ , then full conservation is not an equilibrium, with or without the tax scheme.

When fishers have concave exit options, the effect of asymmetric enforcement is qualitatively similar to the results given in Proposition 11, but weaker. The fisher who is taxed may still find it worthwhile



to play the exit strategy, although there exist levels of wealth at which he would do so in the unregulated game and would not in the regulated tax-scheme game. Similarly the fisher with the ability to tax, even if better endowed, may still find it more profitable to pursue the exit strategy (specifically if  $e^t < e^*$ ). Convex exit option functions complicate the foregoing results. Suppose that the situation is illustrated by Figure 6, and that fisher 1 has wealth  $D$  and fisher 2 has wealth  $C$ . Then conservation is not an equilibrium: fisher 2 is willing to conserve conditional on 1's conservation, but 1 prefers the exit strategy. If, as in Proposition 11, we endow the wealthier fisher 2 with the power to tax fisher 1's first-period catch, 2 will still prefer the exit strategy. (He now has the option of not fishing in period 1 — which would have yielded him  $F$  — and letting fisher 1 fish to capacity in 1 and collecting that catch — which yields him  $F$ .) However, if we grant the poorer fisher 1 with the power to tax fisher 2's first-period catch, then full conservation may be the outcome if the value of 2's exit option is not too high: precisely stated, if

$$\psi(e^2) \leq \frac{e^2}{E}GF \leq F + \psi(e^2)$$

then 2 will be dissuaded from playing the exit strategy. Thus, in the case of the convex exit option, it still matters to *whom* the asymmetric enforcement capability is given; but here the outcome is the opposite of the concave exit option case. Here the poorer fisher is better able to enforce resource conservation.

Granting to the poor the power to tax the rich can be interpreted as a consequence of democracy. Bardhan (1993) discusses the democratization of environments in which traditional authority structures have previously enforced cooperative agreements. Until democracy is consolidated, cooperative performance of resource users may suffer. The result above shows that this may depend on the nature of the exit options open to the rich. If the exit option functions of the rich are convex, then giving the poor the power to tax the rich may not prejudice cooperative behavior. If, however, exit option functions are concave, cooperation may break down.

Taxation of first-period catch, not surprisingly, can be used to make full conservation a self-enforcing equilibrium. Proposition 11 illustrates that even one-sided enforcement of such a tax scheme can lead to equilibrium conservation. However, the proposition also illustrates that this result depends on *which* fisher is given the unilateral power to tax. This is further complicated by the nature of exit options. Where there are no exit options, or where the exit options are concave, efficiency results if the inequalities — higher wealth with the ability to tax — are positively correlated. If exit options are convex, efficiency results when inequalities are *negatively* correlated: it is best to let the poor tax the rich.

### 4.3 Redistribution of fish

Finally, it may be the case that fishers can redistribute the second-period catch once the game is over, and that the share accruing to each fisher is a function of his first-period behavior. This covers a very general class of regulatory mechanisms. We restrict our attention to a subset. Assume that the aim of the mechanism is to reduce first-period fishing to zero. If both fish in the first period, both receive their payoffs from the unregulated game, or  $(e^1 F/E, e^2 F/E)$ . If both conserve in the first period, then fisher  $i$  receives a nonnegative share  $\alpha_i$  of  $GF$ , where  $\sum \alpha_i = 1$ . If one fisher  $i$  cheats in the first period, but the other does not, then  $i$  receives some share  $\underline{\alpha}_i < \alpha_i$  of the second-period fish stock. Effectively, up to this point, we have restricted  $\alpha_i$  (and  $\underline{\alpha}_i$ ) to equal  $e^1/E$ .

Under such a rule-complex, full conservation may emerge even if  $G$  is less than the number of players. Define  $A \equiv \sum \underline{\alpha}_i < 1$ . Then, conditional on this rule-complex, full conservation is an equilibrium outcome if

$$G \geq \frac{\min(E, nF)}{F(1-A) + \sum \underline{\alpha}_i \min(e^i, F)} \quad (9)$$

The right-hand-side of (9) may be less than  $n$  if  $\min(E, nF) = E$ .

We will make several simple comparative-static statements regarding the effect of changes in the distribution of wealth on the range of admissible  $\alpha$ 's.

When fisher 1 decides whether or not he will be better off under the fish-redistribution scheme, he compares his payoff under the scheme and his payoff if he chooses to fish to capacity in the first period. He will agree to the scheme if

$$\alpha GF \geq \min(e^1, F)$$

Likewise, fisher 2 will agree to the scheme if

$$(1 - \alpha)GF \geq \min(e^2, F)$$

Taken together, these conditions require that

$$\frac{\min(e^1, F)}{GF} \leq \alpha \leq \frac{GF - \min(e^2, F)}{GF} \quad (10)$$

We must consider three cases. Case (i):  $e^1 < F, e^2 < F$ . Then condition (10) becomes

$$\frac{e^1}{GF} \leq \alpha \leq \frac{GF - e^2}{GF}$$

If there exists an  $\alpha$  which satisfies this condition, it must be that  $GF - e^2 \geq e^1$ , which in turn implies that  $GF \geq E$ . But this is ruled out by our ‘‘commons assumption’’ (1), except when  $GF$  is

identically equal to  $E$ . Except in this last-mentioned case, there is no value of  $\alpha$  such that a first-best can be implemented in case (i).

Case (ii):  $e^1 \geq F, e^2 \geq F$ . In this case, condition (10) becomes

$$\frac{1}{G} \leq \alpha \leq \frac{G-1}{G}$$

Such an  $\alpha$  exists only if  $G \geq 2$ .

Case (iii):  $e^1 < F, e^2 \geq F$ . Any  $\alpha$  must satisfy

$$\frac{e^1}{GF} \leq \alpha \leq \frac{G-1}{G}$$

This requires that  $F(G-1) > e^1$ , which is true by assumption. So there is always a range of  $\alpha$ 's which can be implemented in case (iii). Note that as fisher 1's wealth is increased, the minimum  $\alpha$  increases as well. This is not so in case (ii), where the range of implementable  $\alpha$ 's is insensitive to the wealth distribution.

If the fishers have exit options, then condition (10) becomes

$$\frac{\min(e^1, F) + \psi(e^1)}{GF} \leq \alpha \leq \frac{GF - \min(e^2, F) - \psi(e^2)}{GF}$$

This does not qualitatively change the discussion. In case (i) there are now strictly no possible  $\alpha$ 's. In case (ii), a range of  $\alpha$ 's exists only if  $G \geq 2$ . Finally, in case (iii) there are still in principle implementable  $\alpha$ 's.

Results like those of Johnson and Libecap (1982) may be characterized as special cases of the approach outlined here. In essence, Johnson and Libecap consider the effect of increasing inequality on the possibility of regulation when there are no sanctions and  $\alpha$  is restricted to be equal to one-half: as inequality is increased,  $\alpha = \frac{1}{2}$  lies outside the set of implementable  $\alpha$ 's.

Kanbur (1991) elaborates an example in this vein. He discusses a two-player commons dilemma and proposes a test to determine whether an efficiency-enhancing rule-complex is possible: compare the payoff accruing to each player under a rent-maximizing outcome to the payoffs under the bad equilibrium. If for some player the latter is higher than the former, then the adoption of a rule-complex is impossible, or less likely. If one player stands to earn less under a cooperative outcome (even though total rent is higher), he will presumably veto the proposed regulatory scheme. Kanbur does not discuss whether or not a cooperative maximum is an equilibrium (as we have done above); if it is not, then even if both players earn more under the cooperative outcome than they do under the bad equilibrium, there is no guarantee that each would not do better by unilaterally deviating.

Kanbur’s criterion should thus be interpreted as a weaker condition on the adoption of a regulatory rule—complex than our condition (10) above.

Some might argue that inequality in this “gain from cooperation” defined by Kanbur may be important independently of wealth inequality. Let us define this gain, normalized by  $GF$ , as  $\delta_i$ :

$$\delta_i = \alpha_i G - \frac{e^i}{E} \tag{11}$$

(11) shows that  $\delta_i$  is increasing in the share of second-period catch accruing to  $i$  ( $\alpha_i$ ) and decreasing in  $i$ ’s wealth ( $e^i$ ). Thus  $\delta_i$  introduces an additional source of inequality, inequality in  $\alpha_i$ . Under uniform-quota regimes of the type which interest Kanbur and Johnson and Libecap,  $\alpha_1 = \alpha_2 = 1/2$ . In such cases, any inequality in  $\delta_i$  is homeomorphic to inequality in wealth endowments. Consider another possible set of values for  $\alpha_i$ ,  $i = 1, 2$ : each fisher gets a proportion of the optimum catch equal to  $e^i/E$ , just as he would in the unregulated game. In this case too, there is no inequality in  $\delta_i$  independent of inequality in wealth endowments. Thus — for our model — inequality in  $\delta_i$  is relevant independently of inequality in wealth only if  $\alpha_1 \neq \alpha_2$ , and  $\alpha_i \neq e^i/E$ . Let us replace our criterion in condition (10): now our criterion is that  $\delta_i$  should be positive for both players. Not surprisingly, for any  $G \geq 1$ , there always exists some  $\alpha$  such that  $\delta_i \geq 0$  for both fishers. Since we define  $G$  to be always at least one, this means that this condition is always satisfied. It may be, of course, that where there are vast disparities in  $\delta_i$ , players are less willing to cooperate for reasons that are not strictly economic, but we are not considering such explanatory rationales in this paper.

These three mechanisms — wealth redistribution, taxes, and fish redistribution — do not in general have identical domains. That is, if conservation is not an equilibrium outcome in the unregulated game, taxation of first-period catch can elicit conservation in situations where the other mechanisms cannot. However, pre-play wealth redistribution and post-play fish redistribution are in general redundant; neither can elicit equilibrium conservation in a situation where the other cannot.

## 5 Extensions of the model

In this Section, we briefly discuss some of the possible ways of extending the basic model of this paper.

### 5.1 Other common-pool resources

The results of this paper will be more useful if they are applicable not only to fisheries, but also to the general class of common-pool resource problems in poor agrarian economies. These include:

community grazing lands, community threshing grounds, communally-exploited forests, and water supplies (whether groundwater, river diversion, or reservoirs) for irrigation. These cases are qualitatively similar to that of the fishery. In most of these examples, there is a resource stock  $F$ , with a regeneration rate  $G$ , and efficiency requires that exploitation be restrained. (While this is true of groundwater exploitation, in other types of irrigation systems, resource-using actions taken this period do not necessarily affect the supply of water in the next period.) The results of this paper regarding resource conservation can be extended to these other settings.

All of the above-named examples, nevertheless, differ in an important respect from the fishery. In addition to resource exploitation, agents must decide on levels of maintenance effort that they will supply in a *cost-sharing* phase. Grazing lands require weeding and repair of fences. Irrigation canals must be cleaned. Fire control measures must be taken in community forests. The cost-sharing problem is a pure public goods one: any one agent's supply of maintenance effort increases the productivity of the system for all others, and the others cannot, in general, be prevented from consuming the higher efficiency of the system.

By focusing on the fishery, we have abstracted from the public-goods problem in order to analyze the conservation problem. However, in models like ours, the supply of a public good is analytically identical to exercising restraint in resource use. Nevertheless, we concede that in real-world common-pool resources, there are important differences between compelling resource users to provide something costly to themselves, and compelling them *not* to do something. In our model, adding a cost-sharing phase simply makes "cooperation" (which now means both full conservation *and* efficient supply of maintenance effort) more costly than previously. Thus qualitatively similar results could be derived, but cooperation may also be more difficult, in the sense that the minimum  $G$  necessary for full conservation (and efficient maintenance) will be higher than in Proposition 2.

## 5.2 Other mechanisms

In this paper, we have focused on particular mechanisms linking inequality and economic behavior. Readers familiar with the case-study literature will recognize that there are other such mechanisms. In particular, social norms (internalized codes of conduct) can be powerful enforcers of cooperative agreements, but this power may be attenuated in extremely unequal environments. Individuals may observe certain cooperative norms, but only in relation to the set of individuals they regard as their peers.<sup>14</sup> Furthermore, it may be that inequality affects the level of enforceability of a socially regulated solution. Assume that there are two means of enforcing the outcome: peer monitoring and

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<sup>14</sup>The evolution of such social norms in the CPR context is treated in Sethi and Somanathan (1996).

more costly hired guards. With the approach to norms mentioned above, there is weak inter-class solidarity but there is strong intra-class solidarity. Thus, with greater equality, overall costs are lower; this is an example of transaction costs differing with the level of inequality. We intend to pursue these avenues in future research.

## 6 References

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## Appendix

In this Appendix we have collected the proofs of the propositions. The equation numbering continues that of the paper.

**Proof of Proposition 1:** Suppose fisher 1 plays  $e^1$ . Then fisher 2's choice is between conservation, which yields the following payoff

$$\frac{e^2}{E}G(F - e^1) \tag{12}$$

and depletion, which yields

$$\frac{e^2}{E}F \tag{13}$$

Given that  $e^i > F(G - 1)/G$ , then (12) is strictly less than

$$\frac{e^2}{E}G(F - F(\frac{G-1}{G})) = \frac{e^2}{E}F$$

which is (13). Thus fisher 2's payoff to depletion is larger than his payoff to conservation, given that fisher 1 has chosen depletion. The argument is the same for fisher 1. Therefore  $\{e^1, e^2\}$  is a Nash equilibrium. ■

**Proof of Proposition 2:** Suppose that  $k^1 = k^2 = 0$  is an equilibrium. If fisher 1, say, deviates and plays  $k > 0$  in period 1, he will receive a total payoff of  $k + e^1 G(F - k)/E$ . Since  $k^1 = k^2 = 0$  is a Nash equilibrium, this must be no better than the payoff he would receive under the equilibrium, namely  $e^1 GF/E$ . That is,

$$\begin{aligned} e^1 \frac{GF}{E} &\geq k + e^1 \frac{G(F - k)}{E} \\ e^1 \left( \frac{GF}{E} - \frac{G(F - k)}{E} \right) &\geq k \\ e^1 \frac{Gk}{E} &\geq k \Rightarrow e^1 \geq \frac{E}{G} \end{aligned}$$

Now suppose that  $e^i \geq E/G$  for  $i = 1, 2$ . Suppose that 2 plays 0 and that 0 is not a best reply for 1. Then there is some  $k > 0$ , such that  $k$  is a best reply for 1. If so, then

$$e^1 \frac{GF}{E} < k + e^1 \frac{G(F - k)}{E}$$

which implies  $e^1 < E/G$ , a contradiction. ■

**Proof of Proposition 3:** The fisher with zero wealth is indifferent between conservation and depletion. The fisher with all the wealth prefers to harvest the fish stock in period 2 (when it is equal to  $GF$ ) rather than harvest it in period 1 (when it is equal to  $F$ ), as long as  $G$  is at least one. Thus full conservation is an equilibrium. ■

**Proof of Proposition 4:** Let us restrict attention, without loss of generality, to the case where fisher 1 is the larger fisher. Say that fisher 2's endowment is  $\epsilon$ , and assume furthermore that  $\epsilon < F$ . If fisher 2 plays his full capacity in period 1, then fisher 1's payoff from full conservation is

$$\frac{E - \epsilon}{E}G(F - \epsilon) \tag{14}$$

and his payoff from playing his full capacity in period 1 is

$$\frac{E - \epsilon}{E}F \tag{15}$$

(14) is larger than (15) if

$$\epsilon \leq \frac{G-1}{G}F$$

Therefore define

$$\hat{\epsilon} \equiv (E - \frac{G-1}{G}F, \frac{G-1}{G}F)$$



Given that  $E > F$ , this distribution in fact endows fisher 1 more handsomely, as we have assumed. We have shown so far that full period-1 conservation is always a best reply for fisher 1 to full-capacity fishing by fisher 2 in period 1. Note that with the distribution given by  $\hat{e}$ ,  $E - \epsilon > E/G$ , so that by Proposition 2, full conservation is also a best reply by fisher 1 to full conservation by fisher 2. Then for any redistribution of wealth away from fisher 2, fisher 1 will always play 0 in the first period, and thus, regardless of fisher 2's strategy, the amount of fish conserved until the second period will be larger. ■

**Sketch of a proof of Proposition 5:** The proof is very simple and will not be given in full. If condition 3 of the proposition is satisfied, then the depleting coalition leaves some fish to regenerate between periods; if 3 is not satisfied, then the only equilibrium is full depletion in period 1. Say that the fishers in  $\hat{I} \subset I$  fish to capacity in period 1, and that 3 is satisfied. Then a fisher  $j$  not in  $\hat{I}$  gets payoff

$$\frac{e^j}{E}G(F - \sum_{i \in \hat{I}} e^i) \quad (16)$$

from conserving, and fishing to capacity in period 1 yields him

$$\frac{e^j}{E}G(F - \sum_{i \in \hat{I}} e^i - e^j) + e^j \quad (17)$$

Now (16) is at least as large as (17) if and only if:

$$e^j \geq E/G$$

By similar logic, if a fisher  $k$  nominally in  $\hat{I}$  is deciding between conserving or depleting, the condition for staying in  $\hat{I}$  is that  $e^k < E/G$ . ■

**Proof of Proposition 6:** In each case that follows, consider a transfer from fisher  $j$  to fisher  $k$ . If  $k \in \tilde{I}$ , then  $k$  will always conserve regardless of the choices made by other fishers. To see this, consider  $k$ 's choice. Say that all other fishers fish to capacity in period 1, and that  $E_{-i} \equiv \sum_{i \neq j} e^i$  is the sum of wealth held by all other fishers. Furthermore, assume that  $E_{-i} < F$ . Then if  $k$  chooses to conserve, his payoff is

$$\frac{e^k}{E}G(F - E_{-i}) \quad (18)$$

while if  $k$  fishes to capacity in period 1, his payoff is  $\frac{e^k}{E}F$ . Now (18) is at least as large as  $\frac{e^k}{E}F$  if

$$E_{-i} \leq \frac{F(G-1)}{G} \quad (19)$$

Now since  $e^k = E - E_{-i}$ , (19) is equivalent to

$$e^k = E - E_{-i} \geq E - \frac{F(G-1)}{G} \quad (20)$$

But (20) always holds by  $k$ 's inclusion in  $\tilde{I}$ . Thus for any fisher with wealth sufficiently great to be in  $\tilde{I}$  conservation is a dominant strategy.

Now consider an unequalizing transfer to such a fisher  $k$ . The result of such a transfer is that the fisher  $j$  who loses wealth must reduce first-period fishing one-for-one with his wealth reduction;  $k$  waits to deploy his wealth until the second period. Thus period-1 fishing is strictly decreased and equilibrium efficiency is strictly increased.

We must also consider unequalizing transfers from fishers  $j \in J$  to fishers  $k$  not in  $\tilde{I}$ . If  $k \in J$ , then  $e^k < E/G$ . After the transfer  $\eta > 0$ ,  $j$ 's period-1 fishing is decreased by  $\eta$ . If  $e^k + \eta \geq E/G$ , then  $k$  may choose to conserve and equilibrium efficiency is strictly increased. If  $e^k + \eta < E/G$ ,  $k$  will increase his period-1 fishing by  $\eta$  and aggregate period-1 fishing (and thus equilibrium efficiency) is unchanged. Suppose finally that  $k$  is neither in  $J$  nor  $\tilde{I}$ . As before

$j$  will decrease his period-1 fishing by  $\eta$  after the transfer. If  $k$  conserves in equilibrium before the transfer,  $k$  will continue to do so after the transfer; aggregate period-1 fishing is decreased by  $\eta$ . If  $k$  did not conserve before the transfer, he may now find it optimal to do so, and equilibrium efficiency is increased. If  $k$  did not conserve before the transfer, and still chooses not to after the transfer, his increased fishing exactly offsets  $j$ 's reduction and equilibrium efficiency is unchanged. ■

**Proof of Proposition 7:** Assumptions (3), (4) and (5) together imply that condition (2) is satisfied as an equality for fisher  $i$  at two points: where  $e^i = 0$  and where  $e^i = e^*$ , for some  $e^* > 0$ . Moreover, for values of wealth such that  $0 < e^i < e^*$ , condition (2) does not hold, while for values of wealth such that  $e^i \geq e^*$ , condition (2) does hold. Consider two cases. (i) Full conservation is an equilibrium under  $e$ . Then it must be that both fishers have wealth greater than  $e^*$ . Then transfer from one fisher to another an amount such that the first's wealth is now below  $e^*$ . Then for the first fisher, condition (2) does not hold, and conservation is not an equilibrium. (ii) Full conservation is not an equilibrium under  $e$ . Then it must be that at least one fisher's wealth lies below  $e^*$ . Then for any transfer from that fisher to the other, so long as the first still has positive wealth, the wealth distribution will be more unequal, and conservation will not be an equilibrium. ■

**Proof of Proposition 8:** Given that the fishery is economically viable (assumption (6)), the fisher with all of the wealth prefers conservation to the exit strategy. The fisher with zero wealth is, by assumption (5), indifferent between conservation and the exit strategy. Therefore full conservation is an equilibrium. ■

**Proof of Proposition 9:** If average wealth is less than  $e^*$ , then under perfect equality the distribution is given by  $(E/2, E/2)$ , and  $e^* > E/2$ . Then for neither fisher does condition (2) hold; that is, conditional on the other fisher's conservation, each fisher would prefer the exit strategy. Thus full conservation is not a Nash equilibrium. ■

**Proof of Proposition 10:** We will prove the contrapositive of the proposition: that is, we will show that if under perfect inequality, full conservation is not an equilibrium, then there exists no other wealth distribution (such that both fishers have positive wealth) under which full conservation is an equilibrium. Suppose that wealth is equally distributed, so that  $e = (s, s)$ , and that full conservation is not an equilibrium. There are three possible cases. (i)  $\psi(e^i) + \min(e^i, F) > (e^i/E)GF$  for all values of fisher  $i$ 's wealth,  $i = 1, 2$ . In this case, both fishers always prefer the exit strategy at all positive levels of wealth, so there is no full-conservation equilibrium. Now if the condition  $\psi(e^i) + \min(e^i, F) > (e^i/E)GF$  is not met, then given the convexity of  $\psi(\cdot)$ , there is some range of wealth levels over which

$$\frac{e^i}{E}GF \geq \psi(e^i) + \min(e^i, F) \quad (21)$$

Say that  $\underline{e}$  is the lowest level of wealth for which (21) is true, and  $\bar{e}$  is the highest level of wealth for which (21) is true. Then if under the distribution  $e = (s, s)$ , full conservation is not an equilibrium, it must be either that  $s < \underline{e}$  or  $s > \bar{e}$ . These are the two remaining cases that we have to consider. (ii)  $s < \underline{e}$ : All other wealth distributions are mean-preserving spreads of  $e$ . If wealth is taken from fisher 1, say, and given to fisher 2, it may be that 2's wealth eventually passes  $\underline{e}$ , so that 2 would be willing to conserve, conditional on 1's conservation. But 1's wealth will always be less than  $\underline{e}$ , and given our restriction that both players' wealth always be positive, 1 will for all wealth less than  $s$  prefer the exit strategy. So full conservation is not an equilibrium for any wealth distribution other than  $e$ . (iii)  $s > \bar{e}$ : Then, once again, all other distributions are mean-preserving spreads of  $e$ . If wealth is given to player 2, the exit strategy will continue to dominate conservation for 2, regardless of 1's strategy. Thus under no spreads of  $e$  is full conservation an equilibrium. ■

**Proof of Proposition 11:** (i)  $i = t$ . Because  $e^i > E/G$ , by Proposition 2, fisher  $i$  will conserve conditional on  $j$ 's conservation. Furthermore, fisher  $j$  now strictly prefers conservation conditional on  $i$ 's conservation. Thus full

conservation is an equilibrium. (ii) If  $i \neq t$ , and conservation is not initially an equilibrium, then by Proposition 2 it must be that  $e^i < E/G$ . Fisher  $j$ 's wealth may or may not exceed this threshold, but given the new tax scheme,  $j$  strictly prefers to conserve conditional on  $i$ 's conservation. However, conditional on  $j$ 's conservation, fisher  $i$ 's payoff is greater if  $i$  fishes to capacity in period 1. (In fact,  $i$  would like  $j$  to cheat in period 1 so that  $i$  could collect the fine!) Thus full conservation is not an equilibrium. ■