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INEQUALITY AND CONSERVATION ON THE LOCAL COMMONS: A THEORETICAL EXERCISE*

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To analyse the effect of asset inequality on co-operation within a group, we consider a two-player nonco-operative model of conservation of a common-pool resource. Overexploitation by one user affects another's payoff by reducing the next-period catch. We give necessary and sufficient conditions such that conservation is a Nash equilibrium, and show that increasing inequality does not, in general, favour full conservation. However, once inequality is sufficiently great, further inequality can raise efficiency. Thus, the relationship between inequality and economic efficiency is U-shaped. Finally, we analyse the implications for conservation if players have earning opportunities outside the commons.

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. Understanding the factors that lead to success or failure of community management of these resources is thus critical to rural development.

CPR management is a collective-action dilemma: a situation in which mutual co-operation is collectively rational for the group as a whole, but individual co-operation is not necessarily individually rational for each member. One factor that has not always been recognised as critical to the outcome of collective action dilemmas is heterogeneity among the resource users. In this paper, our attention will be largely restricted to a single but potent kind of heterogeneity: inequality in asset ownership.

Olson (1965) hypothesised that inequality might favour 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 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 (p. 34).

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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 *et al.* (1986) show that wealth redistributions that increase the wealth of equilibrium contributors to a public good will increase the supply of the public good. In another public-good-provision game, Itaya *et al.* (1997) show that income inequality, if it is so high that only the rich contribute to the public good, raises welfare relative to the regime where all individuals contribute.

These analyses of the 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 local management of CPRs. Indeed, Baland and Platteau (1997) argue that inequality in resource-use entitlements is associated with higher conservation in some examples where the resource-use technology (eg, fishing, harvesting, gathering) exhibits decreasing returns to effort. (Under alternative cases featuring increasing returns to effort, the effect of increasing inequality is indeterminate.)

Nevertheless, field studies of CPR management have repeatedly shown that inequality is harmful for collective action.[1] What is the effect of inequality on the commons? Can a single model capture both the 'Olson effects' – the positive effect of inequality – and allow for the harmful effects of inequality demonstrated in the empirical literature?

This paper presents a simple two-period, two-player model of heterogeneous resource users in a local commons dilemma. The model is couched in terms of a fishery; thus the players are referred to as fishers and the resource as the fish stock. Fishers' catch is a linear and increasing function of their wealth levels (which can be interpreted as 'fishing capacity'). If there is overfishing, each fisher's payoff is proportional to his share of total wealth. The Pareto-optimal outcome is no fishing in the first period and depletion of the larger second-period fish stock. We chose the fishery example primarily 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. Moreover, recent research suggests that the link between inequality and conservation on the commons has macroeconomic implications, drawing an analogy between the commons and economic growth (Benhabib and Rustichini, 1996; Tornell and Velasco, 1992). The externality between fishers in our model differs from the usual congestion externality posited in commons research. In our model, one fisher's overexploitation affects another's incentives through payoffs in the following period, while the conventional congestion externality acts through increased harvesting costs during this period.

[1] The harmful effects of inequality can be gleaned from the following surveys. Bardhan (1995) reviews the case-study literature regarding the relationship between inequality and co-operation in locally-managed irrigation systems, primarily in Asia; Bardhan and Dayton-Johnson (2002) survey the large-scale quantitative research on heterogeneity and co-operation in such irrigation systems. Baland and Platteau (1996; 1997; 1998) likewise summarise many relevant examples from the case-study literature; they focus on forests, fisheries and grazing lands, and on African cases.

In the paper, we demonstrate that Olson's (1965) hypothesis – interpreted as a comparative-static statement that increasing inequality enhances efficiency – is not 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 favours 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.

Olson's 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. Thus, we concur with Olson that the larger player, in many settings, has a greater interest in collective action than the smaller player. It does not necessarily follow, however, that a more unequal distribution of wealth (making one player 'larger') will lead to more successful collective action. The paper provides several instances in which widening wealth disparity is bad for conservation.

A significant result is that the relationship between inequality and collective action is not necessarily monotonic. In fact, the relationship is U-shaped: at very low and very high levels of inequality, conservation is possible, while, for some middle range of inequality, it is not. The U-shaped feature of our model is consistent with recent empirical research on large numbers of community irrigation systems in South India (Bardhan, 2000) and infrastructure projects in North Pakistan (Khwaja, 2000) that find evidence of a U-shaped relationship between measures of inequality among commons users and measures of successful commons outcomes.

The intuition behind the U-shaped result is the following. At perfect wealth equality, conditional conservation is a best response for each fisher to conditional conservation by the other, as long as each fisher's wealth level exceeds a threshold defined in terms of the model's parameters. ('Conditional conservation' means simply conserving when one's counterpart conserves.) Mean-preserving spreads of the wealth distribution will reduce one fisher's wealth to the point where his claim on the final-period fish stock provides insufficient incentive to conserve. As the wealth distribution becomes even more unequal, however, conservation becomes a dominant strategy for the wealthier fisher. The poorer fisher's inefficient period-one fishing is too small (because his fishing capacity is so small) to dissuade the wealthier fisher from conserving. Beyond a certain threshold, then, the more unequal the wealth distribution, the smaller the amount of inefficient first-period fishing that occurs. In the limit, one fisher has monopoly rights over the fishery and first-best efficiency is restored.[2] (The U-shaped result can be generated with or without exit options for the fishers.)

The results of the paper, of course, depend on a type of failure of the standard Coase theorem. Clearly, investigating the effect of endowment inequality on economic performance is salient only when credit or rental markets are not perfect. Otherwise, suitable leasing of boats would work around the problems highlighted herein. Imperfect credit and rental markets, of course, is not an unrealistic assumption in the case of small fishers anywhere in the world, and particularly in poor countries. The underlying mechanisms stem from problems of moral hazard, adverse selection and contract enforcement. Although we assume away credit or rental markets for the sake of simplicity, the qualitative results are likely to remain unchanged if, for example, we were to make the more realistic assumption that how much one can borrow or rent depends on initial wealth levels.

The outline of the paper is as follows. Section 1 sketches a basic nonco-operative commons game. We extend the basic game in Section 2 to consider the effects on conservation if players have earning opportunities outside the commons. The two-player model we use in this paper contributes to the tractability of the analysis and the transparency of the results. A two-player model abstracts from the group-size problem highlighted by Olson (1965) to focus on the problem of inequality better. Section 3 briefly considers schemes for community regulation of the commons in light of the nonco-operative model, and concludes.

1. A Simple Model of the Commons

1.1. *The Basic Model*

There are two fishers, $i = 1, 2$, each endowed with wealth e_i. 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 a_i^t; thus $a_i^t \leq e_i$. (a is short for 'action.') Each fisher's utility is simply the total amount of fish he catches:

$$U_i = \phi_i^1(a_i^1, a_j^1) + \phi_i^2(a_i^2, a_j^2)$$

[2] The U-shaped relationship could be generated in more general models of public-good provision, as in the 'ballroom-dancing' model of Bliss and Nalebuff (1984). In their model, different agents can supply a public good, paying all the cost. They play a game of attrition and, eventually, the lowest cost actor provides the good. If the public good can be provided in variable quantities (as is the case, for example, of a library), then lowest cost actor pays something first; but then later actors can add to the fund. In this case offsetting effects will generate a U-shaped feature, as in our model. Supposing a bounded support, great inequality entails that one actor at least has low cost so he will act quickly. And if he alone is effectively deciding the scale of the project, he is motivated to make it large. Now suppose, instead, that there are two such large players, close together in costs. The Nash effect now encourages them to free-ride and give less. Even so, two relatively small donations may add up to more than one donation. Under near equality, costs are closely bunched on a narrow uniform distribution. Whatever one player's costs, it is likely that many other players have lower costs. This provides an incentive to wait for the others to donate and free-ride really strongly in choosing one's donation. Our thanks to Christopher Bliss for suggesting this interpretation.

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

$$\phi_i^1(a_i^1) = \begin{cases} a_i^1 & a_1^1 + a_2^1 \leq F \\ \dfrac{a_i^1}{a_1^1 + a_2^1}F & a_1^1 + a_2^1 > F. \end{cases}$$

Between periods, the stock of fish grows at rate $g \geq 0$, so that, in period 2, the supply of fish is $G(F - \phi_1^1 - \phi_2^1)$, where $G \equiv 1 + g$. In the second period, each fisher again chooses a capacity level a_i^2. 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 labour. 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 consisting of the second period, both fishers will always fish to capacity. That is, each will choose $a_i^2 = e_i$ and receive second-period payoff

$$\phi_i^2 = \frac{e_i}{E}G(F - \phi_1^1 - \phi_2^1).$$

Thus we can concentrate on the fishers' actions in the first period. A strategy is just a capacity choice a_i^1, and the first-best outcome is $a_1^1 = a_2^1 = 0$. Any Nash equilibrium of the abbreviated first-period game, together with full depletion of the stock in the second period, will be a subgame-perfect equilibrium of the full game. For simplicity, we will hereafter suppress the period superscript, since all strategic choices under consideration are made in period 1. (If, contrary to our assumption, G were less than 1, there would be no real dilemma: first-period depletion of the resource would be an equilibrium outcome and an optimum.) The crowding externality that is sometimes a feature of commons models does not occur in our model *within* periods. That is, j's action in period 1 does not enter i's payoff in that period, although j's period-1 action will enter i's period 2 payoff, and *vice-versa*.

The goal of conservation in fisheries is to secure a reasonable long-term yield (ideally, maximum sustainable yield, or maximum economic yield). In our simple model, that level has been normalised 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 forgo current-period consumption in return for higher next-period gains?[3]

In this model, we abstract from the problem of discount rates so as to focus more clearly on the incentives toward resource conservation. Formally, a positive 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, each fisher's discount rate is plausibly a decreasing function of wealth. In this case, the more unequal the distribution of endowments, the more difficult it will be to sustain universal conservation of the resource. It is as if the poor fisher faces a lower rate of growth in the stock and hence has less incentive to conserve.

In this simple game, each player i chooses effort level a_i: if $a_j \in [0, F - a_i]$, then the fish stock is not depleted in period 1; if, however, $a_j \in [F - a_i, e_j]$, then the fish stock is depleted in period 1. (Either of these intervals could be empty.) The following lemmas establish the characteristics of the fishers' best-response functions, in preparation for Proposition 1, which characterises the set of equilibria. (All proofs are found in the Appendix.)

LEMMA 1 *If, for fisher i, the interval* $[F - a_j, e_i]$ *is non-empty, then i's optimal choice on it is* $a_i = e_i$.

Now consider the interval $[0, F - a_j]$. On this set, fisher i's payoff is strictly linear in a_i, and the slope of his utility function is

$$s_i \equiv 1 - \frac{e_i}{E} G$$

We assume that e_i, E, and G are such that $s_i \neq 0$ for $i = 1, 2$. Lemma 2 shows that if fisher i's payoff is positively-sloped, then $a_i = e_i$ strictly dominates all other strategies.

LEMMA 2 *If* $s_i > 0$, *then* e_i *is the unique best response to any action* a_j *chosen by fisher j.*

LEMMA 3 *Let* $s_i < 0$.

(*a*) *If* $e_i \leq F - a_j$, *then i's best response is* $a_i = 0$.
(*b*) *If* $e_i > F - a_j$, *the best response is* 0, e_i, *or both* 0 *and* e_i *as*

$$\frac{e_i}{E} G(F - a_j) \tag{2}$$

is greater than, less than, or equal to

$$\frac{e_i}{e_i + a_j} F \tag{3}$$

respectively.

[3] Other economic treatments of the fishery have focused on changes in the incentives to conserve when the fish population varies (Levhari and Mirman, 1980; Dutta and Sundaram, 1993). This can be approximated in our model by simply varying F as a comparative-static exercise.

LEMMA 4 *There are only four possible equilibria:* $(0,0), (e_1,0), (0,e_2), (e_1,e_2)$.

1.2. *Results of the Basic Model*

With the aid of these lemmas, we are prepared to characterise the set of Nash equilibria to this game, depending on the slopes of the utility functions of the two fishers.

PROPOSITION 1 *The Nash equilibria of the basic game are as follows:*

(*i*) $s_1 > 0$, $s_2 > 0$: (e_1, e_2) *is the only equilibrium, and it is a dominant-strategy equilibrium.*
(*ii*) $s_1 > 0$, $s_2 < 0$: $(e_1, 0)$ *is an equilibrium* $\Leftrightarrow$ *either* $e_2 \leq F - e_1$ *or* $e_2 > F - e_1$ *and* $(G-1)F \geq Ge_1$. (e_1, e_2) *is an equilibrium* $\Leftrightarrow$ $e_2 > F - e_1$ *and* $(G-1)F \leq Ge_1$.
(*iii*) $s_1 < 0$, $s_2 < 0$: $(0,0)$ *is always an equilibrium.* (e_1, e_2) *is an equilibrium* $\Leftrightarrow$ $(G-1)F \leq Ge_i$, $i = 1, 2$.

The structure of the equilibrium set is illustrated in Fig. 1, for fixed $E > F$ and $G > 2$. The length of the horizontal axis is E: reading from the left gives e_1, while reading from the right gives e_2. The vertical axis measures F, which is allowed to vary. The sloping lines correspond to the equations $(G-1)F = Ge_i$, where $i = 1$ for the rising portion and $i = 2$ for the falling portion. The left vertical line separates the region $s_1 > 0$ (on the left) from the region $s_1 < 0$. The right vertical line

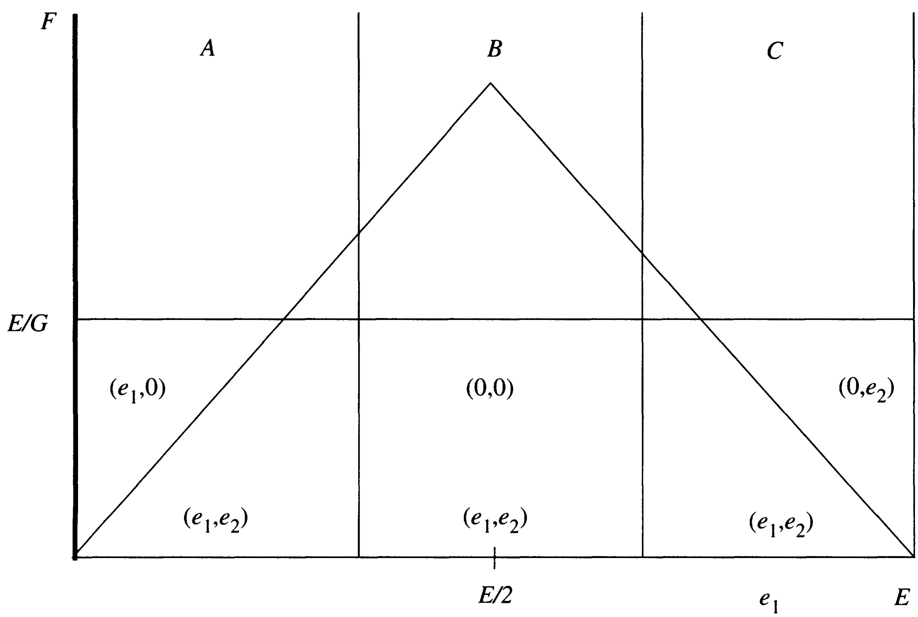

Fig. 1. *Characteristics of Equilibrium Set*

separates the region $s_2 > 0$ (on the right) from the region $s_2 < 0$. Thus the box is divided vertically into three regimes: regime *A*, where $s_1 > 0$ and $s_2 < 0$; regime *B*, where $s_1 < 0$ and $s_2 < 0$; and regime *C*, where $s_1 < 0$ and $s_2 > 0$. The three regions are limited vertically by the constraint that $F \leq E/G$, which follows from the commons-dilemma assumption (1). (The three regimes do not correspond exactly to the three cases of Proposition 1: case (i) is not depicted in Fig. 1, while case (ii) corresponds to regime *A*; case (iii) is depicted as regime *B*. Equilibria are labelled in the relevant regions of the box.)

Proposition 1 illustrates the conditions under which the least efficient outcome $(a_1 = e_1, a_2 = e_2)$ is an equilibrium. Fig. 1 demonstrates that, under any wealth distribution, there exist parameter configurations so that first-period depletion is a Nash equilibrium; nevertheless, for any wealth distribution and any $G > 2$, there exists a sufficiently high level of F such that full depletion is no longer an equilibrium outcome. Proposition 1 also demonstrates the conditions under which first-best efficiency $(a_1 = a_2 = 0)$ emerges as an equilibrium outcome. Corollary 1 states the necessary and sufficient conditions for first-best efficiency in equilibrium:

COROLLARY 1 $(a_1 = a_2 = 0)$ *is an equilibrium if and only if* $e_i > E/G$, *for* $i = 1, 2$.

(This is a straightforward restatement of case (iii) of Proposition 1, using the definition of the slopes s_i.) Intuitively, E/G is the threshold amount of wealth above which the fisher will conserve, conditional on his counterpart's conservation. Alternatively, the condition $e_i \geq E/G, \forall i$ 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 might seem worrisomely high; the astute reader will have, moreover, noticed that the n-player version of Corollary 1 will imply that conservation requires $G \geq n$. This result is quite robust. For any general fishing technology $f(a_i)$ and sharing rule $(\{\alpha_i\}_{i \in I}, \sum \alpha_i = 1\})$ in the case of overcapitalisation, it can be shown that the appropriate generalisation of Corollary 1 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 α_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 3.

Finally, Proposition 1 spells out the parameter combinations under which there are multiple equilibria. In fact, whenever the condition of Corollary 1 is satisfied, there are multiple equilibria.

COROLLARY 2 *Both full depletion and full conservation are equilibrium outcomes if* $e_i > E/G$, *for* $i = 1, 2$.

Fig. 1 illustrates the possibility of multiple equilibria under regime *B*.

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. Proposition 2 below suggests that this is not so. Define

$$\Delta(E) \equiv \{(e_1, e_2)|e_1 > 0, e_2 > 0, e_1 + e_2 = E\}$$

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 $|\hat{e}_1 - \hat{e}_2| > |e_1 - e_2|$. In Fig. 1, a mean-preserving spread is a movement to the right along the horizontal axis starting anywhere to the right of the midpoint $e_1 = e_2 = E/2$, or to the left, starting anywhere from the left of the midpoint.

PROPOSITION 2

(*a*) *Consider* $e, e' \in \Delta(E)$, *where* e' *is a mean-preserving spread of* e. *Then* $(a_1 = a_2 = 0)$ *is an equilibrium under* e' *only if it is an equilibrium under* e.

(*b*) *For all* $e \in \Delta(E)$, *there is a mean-preserving spread* e' *such that* $a_1 = a_2 = 0$ *is not an equilibrium under* e'.

Part (*a*) of the Proposition can be understood in terms of Fig. 1. If full conservation is an equilibrium under e', then e' lies in the middle parameter regime *B*. Suppose, without loss of generality, that e' corresponds to a point to the right of $E/2$ on the horizontal axis. Any $e \in E$ of which e' is a mean-preserving spread must then lie between $E/2$ and e' and therefore must also lie in regime *B*, where full conservation is an equilibrium. 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 Corollary 1 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 Fig. 1, this is equivalent to moving from a point in regime *B* to a point in regime *C*.

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 owns all the wealth – conservation is an equilibrium outcome.

PROPOSITION 3 *In the basic game, if* $G \geq 1$, *then under perfect inequality* $(e = (E, 0)$ *or* $e = (0, E))$, *full conservation is a unique Nash equilibrium.*

In part, Proposition 3 reflects Olson's hypothesis that co-operation 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 outcome. The more realistic case in an unregulated fishery, and one perhaps closer to Olson's thinking, is one in which changes in the distribution of wealth change the level of efficiency among a set of *inefficient* equilibria. This is considered in the following proposition, which says that if the distribution of wealth is sufficiently unequal already, then making 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 such E 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

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

and all mean-preserving spreads of $\hat{e}$, fisher 1 will conserve regardless of the other's behaviour.[4] 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 Corollary 1, 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 further reducing i's capacity, will increase efficiency, since fisher j will play 0 and more fishing will be deferred until the second period. 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 protecting the collective good ... [T]here is accordingly a *surprising tendency for the 'exploitation' of the great by the small* (p. 35, emphasis in the original).

This, then, is the commons analogue of the Olson public-goods hypothesis.

This situation is summarised in Fig. 2, which shows (assuming that $G \geq 2$) 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. Note that this figure depicts, for $e_1/E \leq (G-1)/G$, only the most efficient equilibrium shown in region B of Fig. 1; there is another equilibrium for this configuration of parameters in which fisher 1 will fish to capacity in period 1.[5]

[4] If we restrict the parameters so that $E = FG$, for $G = 2$, the wealth distribution $\hat{e}$ is given by $\left(\frac{3}{4}E, \frac{1}{4}E\right)$. As G is increased beyond 2, $\hat{e}$ becomes more unequal.

[5] This figure was suggested by Jean-Marie Baland.

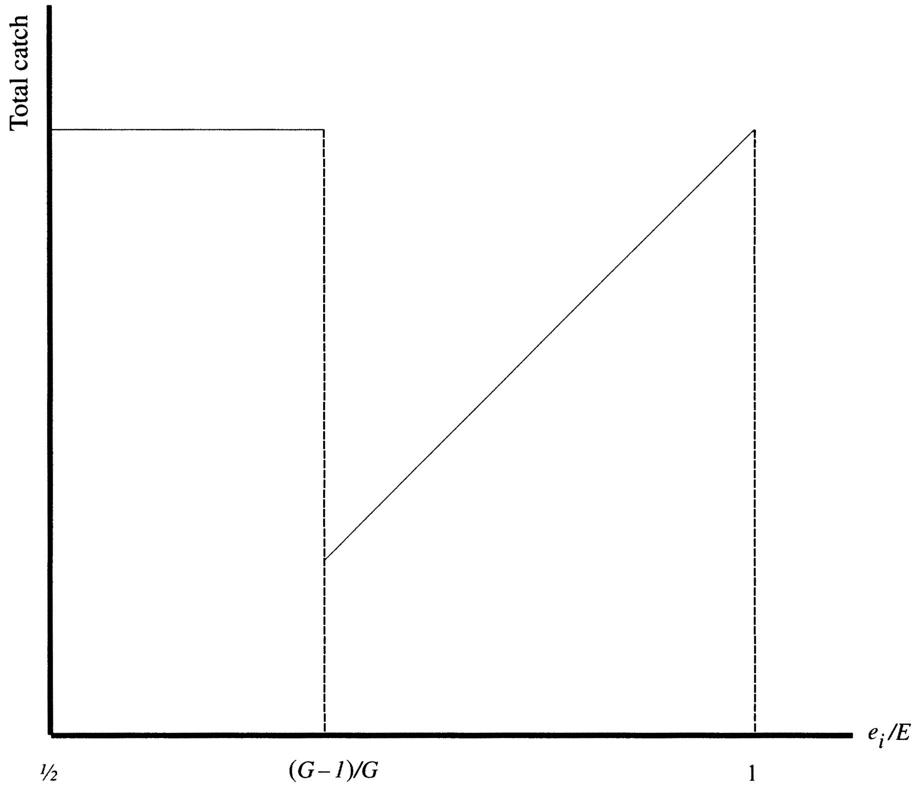

Fig. 2. *Inequality and the Efficiency of Cooperation*

1.3. *More than Two Agents*

Most of our results are not qualitatively changed if there are more than two fishers. Proposition 5 extends both our Corollary 1 and Proposition 4. In what follows, we call any outcome in which some but not all 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 outcome if and only if:*

(a) *for all fishers i in the subset* $\hat{I} \subset I$ *of fishers who do not conserve,* $e_i < E/G$
(b) *for all fishers i in* $I \setminus \hat{I}$, $e_i \geq E/G$
(c) $\sum_{i \in \hat{I}} e_i < F$.

COROLLARY 3 *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 remains an equilibrium outcome.*

(*b*) *There exist efficiency-enhancing mean-preserving spreads of the initial wealth distribution.*

Part (*a*) of Corollary 3 merely states that mean-preserving spreads of the wealth distribution do not necessarily destroy a co-operative 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 can 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 exist wealth-equalising transfers such that full depletion is the only equilibrium outcome under the new wealth distribution. Suppose that $\hat{I}$ is such that $\sum_{i \in \hat{I}} e_i = F - \epsilon$. For depletion to be the equilibrium outcome, the necessary transfer from a fisher $r \in I \setminus \hat{I}$ to a (poorer) fisher $s \in \hat{I}$ is $\min\{T, \epsilon\}$, for some small $\epsilon > 0$, provided that the transfer is feasible (ie, $\epsilon < e_r$). Then an equalising wealth transfer will bring about depletion either because

(i) fisher r will no longer choose to conserve or
(ii) by giving fisher s sufficient capacity to deplete the fish stock.

In case (ii), a transfer of ϵ is clearly sufficient. In case (i), if fisher r conserves, then $e_r \geq E/G$. If fisher r loses wealth T, he will not conserve; thus T must satisfy $e_r - T < E/G$. Hence the wealth transfer necessary to move r into $\hat{I}$ must satisfy $T > e_r - E/G$. To violate condition (*c*) of Proposition 5, the transfer plus the remaining wealth of fisher r must be sufficient to deplete the stock; that is, $e_r - T \geq \epsilon - T$, or $e_r \geq \epsilon$.

Now it remains to generalise 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 characterise 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 $e_j < E/G$ and $e_k \geq E/G$. Fisher j would fish to capacity in period 1 before the transfer, and $e_j \leq e_k$. Call this class of mean-preserving spreads *unequalising wealth transfers*. Many more complicated mean-preserving spreads can be characterised as the outcome of a sequence of such unequalising wealth transfers.

PROPOSITION 6 *In the n-fisher extension of the basic fishing game, define the set*

$$\bar{I} \equiv \left\{ i \in I | e_i \geq E - F\frac{G-1}{G} \right\}$$

and define

$$J \equiv \left\{ i \in I | e_i < \frac{E}{G} \right\}.$$

If $\bar{I}$ and J are nonempty, then after any unequalising 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 (ie, 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.

2. Exit Options

In fisheries worldwide, large fishing companies with more opportunities to move their fleets elsewhere (compared to small-scale local fishers) are much less concerned about conservation of the 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 (1997) cite a similar phenomenon 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; see Shanmugaranam *et 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 agricultural entity known as 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.

In all 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 exercise exit options. 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 harvested by Fulani refugees from Guinea, who are more likely to be landless than other peasants, so as 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; see Laurent *et al.* (1994), cited in Baland and Platteau (1997).[6]

In our extended model with exit options, co-operation is more difficult for the fishers. Moreover, the fisher who exits may be the relatively wealthier or less wealthy of the two, depending on the shape of the exit-option functions.

We 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.[7] 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 depends on a fisher's endowment level: 'exit' could 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 where $\psi(\cdot)$ 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):

$$\frac{e_i}{E} GF \geq \min\{e_i, F\} + \psi(e_i) \qquad \text{for } i = 1, 2. \tag{4}$$

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.

2.1. *Concave Exit Options*

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

$$\psi(e_i) \geq 0, \psi(0) = 0. \tag{5}$$

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

[6] One could argue that this evidence from Guinea and Burkina Faso points as much to the importance of 'sustainability traps' as to that of exit options. That is, those agents with no exit options and no alternatives but non-sustainable resource use will 'hang on to the last straw'.

[7] In our framework, it is not so interesting to explore the consequences if a fisher could exit in period 1. Under the assumptions of our model, if a fisher could exit before fishing in period 1, the other fisher's best response would be to conserve.

$$\frac{e^\star}{E} GF = \min\{e^\star, F\} + \psi(e^\star). \tag{6}$$

If assumption (6) 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.

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

$$\psi(E) \leq (G - 1)F. \tag{7}$$

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.

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 (5) and (6). Then, given any wealth distribution* $e \in \Delta(E)$ *that 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 Corollary 4, which addresses the Olson hypothesis in the context of concave exit options:

COROLLARY 4 *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.*

Corollary 4 says that, when the exit option is a nondecreasing concave function, together with the restrictions implied by assumptions (5) and (6), 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 generalises to the case where only one fisher has an exit option.

The principal issues raised in Proposition 7 and Corollary 4 can be depicted graphically. First note that the Nash-equilibrium condition (4) can be rewritten as

$$\psi(e_i) \leq \frac{e_i}{E} GF - \min\{e_i, F\}. \tag{8}$$

In Fig. 3, fisher i's wealth is given on the horizontal axis, and i's payoff is given on the vertical axis.[8] The right-hand side of (8) is drawn as *ONM*, and the left-

[8] In this figure, 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 can be interpreted as representing the *share* of total wealth held by fisher i when $E = 1$. Unlike Fig. 1, fisher j's wealth is *not* read here from right to left.

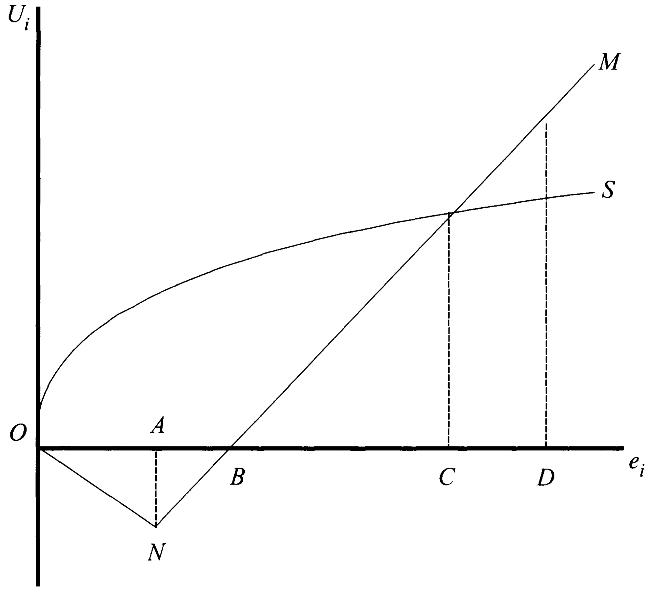

Fig. 3. *A Concave Exit-Option Function*

hand side ($\psi(\cdot)$) is given by the concave function *OS*. Note that the sign of the right-hand side of (8) determines whether full conservation is an equilibrium in the basic (no-exit-option) version of the game introduced in Section 1. From Corollary 1, then, we know that the right-hand side must be positive for all values of e_i greater than E/G, which is labelled *B* in Fig. 3. The point labelled *A* corresponds to *F*, the initial fish stock. *A* is the point of intersection between the lines $U_i = e_i(GF/E - 1)$ to the left (note that the slope is negative as a result of the commons dilemma assumption (1)) and $U_i = e_i GF/E - F$ to the right. The wealth level e^* is labelled *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.

According to Corollary 4, if full conservation is an equilibrium outcome under 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 *D* in Fig. 3. Then by redistributing wealth away from fisher *i* until his wealth lies to the left of *C*, full conservation is no longer an equilibrium; at such a new distribution, *OS* lies above *ONM* for fisher *i*, and he will prefer the exit strategy.

Meanwhile, it can be shown that, in the vein of Olson, *extreme* inequality can *enhance* the prospects for conservation: under perfect inequality, and if assumptions (5) through (7) hold, full conservation is an equilibrium.

2.2. *Convex and Asymmetric Exit Options*

In Proposition 7, illustrated in Fig. 3, the return to the exit strategy, relative to conservation (and always conditional on conservation by the other fisher) is diminishing in wealth: when there is exit, it is the smaller fisher who exits. 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 user who exits. How is the prediction of Proposition 7 reconciled with this empirical evidence? First, it could be that exit options are not concave (or even weakly concave) functions of wealth. Second, it could be that exit option *functions* (and not just the exit-option *values*) are different for the different fishers. Each of these possibilities is considered in turn.

Fig. 4 illustrates a convex exit option function. The principal complication is that there are several 'crossover' points corresponding to the wealth value e^* in the concave case. Thus, for example, begin at a position of perfect *in*equality with total wealth D in Fig. 4; that is, one fisher's endowment is D and the other's is zero. Full conservation is not an equilibrium outcome, 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 outcome. If one fisher's wealth is C while the other's is in the range of A, however, full conservation is not an equilibrium outcome.

Situations like that depicted in Fig. 4 might well describe many commons with exit options. In general, because of the kinked 'convex' shape of the right-hand side of the Nash-equilibrium condition (8), a convex left-hand side of the same condition will cross the right-hand side more than once. With convex exit-option

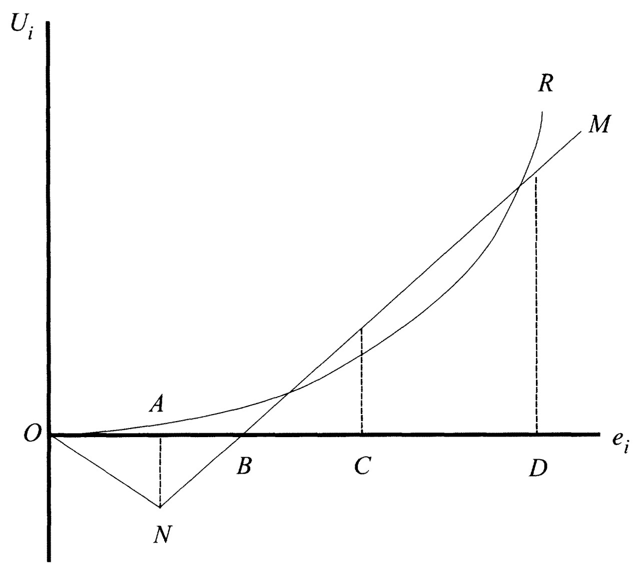

Fig. 4. *A Convex Exit-Option Function*

functions, we can make the following proposition, which does not, in general, hold when exit-options are concave.

PROPOSITION 8 *In the exit-option game where each fisher has an exit option given by* $\psi(e_i)$, *let* $\psi(\cdot)$ *be a convex and increasing function of wealth, and let* $\psi(0) = 0$. *If there exists any wealth distribution* $e \in \Delta(E)$ *such that both fishers have positive wealth and under which full conservation is an equilibrium outcome, then full conservation is not an equilibrium outcome under perfect equality.*

In some commons situations, agents' exit options are qualitatively different. In a particular in-shore fishery, for example, 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 poor fisher tried to do the same in his small primitive boat, he would stand a good chance of dying at sea. More generally, the smaller agent's capacity is location-specific in a way that the larger agent'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. Fig. 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 always conserve if his wealth lies 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 outcome. 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 outcome, unlike the situation described by Proposition 7. Nevertheless, if fisher 2's wealth were reduced to a point between *O* and *B*, he would choose to deviate, and full conservation would not be an equilibrium outcome.

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 unequalising redistribution needed to destroy a full-conservation equilibrium must be *more* unequalising than the minimum necessary redistribution in Proposition 7.

Our earlier assumption that exit-option functions were at least weakly concave made strong comparative-static results possible. In the figures, 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 complicated. If, in the case where there are multiple crossings, conservation is not initially an equilibrium outcome, it is not always possible to say whether it will be an equilibrium outcome under any more (or less) unequal distribution. If the right-hand side of the inequality (8) is also concave (which might occur under considerably more complicated assumptions about the fishing production function), then, even with concave exit-option functions, this can give rise to multiple crossings.[9]

The nature of the exit-option functions is ultimately an empirical question. In many situations, exit-option functions are probably linear beyond some level of wealth – this represents a risk-free bond earning a fixed interest rate. At lower levels of wealth, though, the exit-option function is convex as a result of borrowing constraints. As we have seen, however, in all cases, the presence of exit options generally complicates the prospects for conservation.

3. Concluding Remarks

3.1. *Crafting Distributive Rules*

In real-world commons problems, economic actors often craft institutions to regulate community use of common-pool resources. If the problem is one of multiple equilibria (as is the case in our model when the conditions of Corollary 2 are satisfied), the task of such local regulation is merely to co-ordinate actors on one Pareto-efficient equilibrium. If the problem is a prisoners dilemma (as is the case under other parameter configurations for our model), there must be a structure of rules, very likely with monitoring and enforcement, that transforms the dilemma into a co-ordination game and the Pareto-superior outcome into a self-enforcing equilibrium. (This is essentially the message of Ostrom's (1990) synthesis of studies of local regulation of the commons.) Fishers worldwide have elaborated schemes of social regulation with varying degrees of success; many of these cases are reviewed in Baland and Platteau (1996). In this section, we discuss such regulatory regimes in light of our model.[10]

Fishers in our model might consider three regulatory mechanisms to govern the exploitation of the fish stock: they could redistribute wealth (e_1, e_2) before period 1; they could redistribute catch (ϕ_1^1, ϕ_2^1) after the first period; or they could redistribute fish (ϕ_1^2, ϕ_2^2) after the second period. (Many of the distributive rules described in the field-study literature reallocate fishing *locations*: these can be interpreted as redistributions of capacity. If fishing locations have different productivities, the default share of the fishing stock accruing to each fisher will be different. Note that, for our model to apply, it must also be that the fishing locations are not physically isolated from one another.) Such schemes have two possible effects on the payoff of the game. First, the scheme could impose a fine on the player who does not abide by the co-operative agreement: this reduces the return to cheating. Second, output could be shared in the co-operative outcome

[9] Consistent with the discussion in Bénabou (1996) 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 co-operation.

[10] The working-paper version of this paper, available on request from the authors, includes a much lengthier analysis of these issues, including the details behind several of the assertions made in the remainder of this section.

differently from the default sharing rule of the nonco-operative game (ie, $\{e_i/E\}_{i \in I}$). This change in the sharing rule could arise from redistribution of catch, or from pre-play wealth redistribution.

The results of Section 1 are comparative-static results, but can be reinterpreted as statements regarding redistribution of capacity. Thus, for example, Corollary 1 tells us that for wealth distributions that 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 preplay capacity redistribution 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. Nevertheless, the magnitude of the transfer under a self-enforcing equilibrium is limited; the fisher who cedes wealth must be at least as well off under full conservation, post-transfer, as under full depletion, pre-transfer.

An alternative to pre-play wealth transfers is that fishers effect transfers of fish conditional on the size of individual first-period catch. Effectively, this means that they can tax each other. It is a well-known result in the fisheries literature that if first-period catch can be taxed at a rate of 100%, then a first-best outcome can be implemented under just about any circumstances (including most exit-option scenarios). (This is essentially the same as boat licensing in our model: limiting the number of boats (ie, the proportion of e_i) that each fisher i uses in period 1 is directly related to limiting his catch.) Nevertheless, transaction costs might make it impossible to observe each fisher's period-1 catch and thereby collect taxes. An interesting possibility is that the power to tax is asymmetric; 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. It can be shown that, under certain conditions, if the poorer fisher is given the power to tax the richer, co-operation is not an equilibrium outcome. This result extends to the case of concave exit options. In the case of convex exit-option functions, however, the *poorer* fisher is better able to enforce conservation.

An interesting consequence of democracy is that it grants to the poor the power to tax the rich. Bardhan (1993) discusses the democratisation of environments in which traditional authority structures have previously enforced co-operative agreements. Until democracy is consolidated, co-operative performance of resource users can suffer. ('Resource users' could refer to local villagers sharing a fishery, or to citizens contributing to 'social cohesion'.) The discussion of asymmetric taxation under exit options shows that this depends on the nature of 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 might not prejudice co-operative behaviour. If, however, exit-option functions are concave, co-operation can break down.

Finally, fishers could redistribute the second-period catch once the game is over such that the share accruing to each fisher is a function of his first-period behaviour. 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 $(e_1F/E, e_2F/E)$. If both conserve in the first period, then i receives a nonnegative share α_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 $\underline{\alpha}_i$ of the second-period stock. Effectively, up to this point, we have restricted α_i and ($\underline{\alpha}_i$) to equal e_i/E. It can be shown that under such a rule complex, full conservation can emerge even if $G < n$. However, the range of implementable mechanisms is, under certain circumstances, sensitive to the wealth distribution.

3.2 *Summary of Results*

This paper presents a model of two fishers differentiated by asset-holding levels in an unregulated fishery. Co-operation in this model takes the form of restraint in resource extraction: if both fishers reduce their catch in the first period, they can reap larger rewards after the fish stock has grown. Efficiency is indexed by the amount of the initial fish stock available at the start of the second (and final) period. The model explores the effect of inequality in asset ownership (fishing capacity) on conservation of a common-pool resource. We demonstrate that Olson's (1965) inequality hypothesis interpreted as a comparative-static statement that increasing inequality enhances efficiency – is not strictly correct. We give conditions such that inequality reduces equilibrium efficiency (conservation of the fish stock). If fishers have earnings opportunities outside the commons ('exit options') that are concave functions of wealth, increased inequality can reduce the prospects for full conservation. Furthermore, there exists a wealth distribution beyond which increasing wealth inequality increases equilibrium efficiency (though not attaining full conservation as long as both fishers have positive wealth), and full conservation is an equilibrium under perfect *in*equality. The relationship between inequality and conservation can be U-shaped: at very low and very high levels of inequality, conservation is possible, while for a middle range of inequality, it is not.

The linear technology used in this paper is a simplification that permits us to derive concrete results that usefully extend the commons literature; a completely general cost function would complicate the results considerably. Bardhan *et al.* (2000) undertake the task of constructing a general model of collective goods with strictly concave production (or cost) functions to determine the effect of inequality of initial endowments affects the amount of aggregate surplus. Their results are generally indeterminate: extreme inequality is good for collective good provision, as the dominant player can internalise the externality, but the concavity of the general production function tends to make equality more efficient. The net result depends in complicated ways on the parameters of the production function and of externalities. Moreover, their results are developed only in a one-period case, thus abstracting from the intertemporal externalities that feature in this paper.

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Appendix: Proofs

Proof of Lemma 1 For all $a_i \in [F - a_j, e_i]$, the fish stock will be depleted in period 1; fisher i can increase his payoff only by increasing his share of the catch, and his share is strictly increasing in a_i. Thus he should choose the highest possible level of a_i, namely e_i.

Proof of Lemma 2 Because s_i is positive, then the maximum on the intersection $[0, F - a_j] \cap [0, e_i]$ is $a_i = \min\{F - a_j, e_i\}$. Even if $\min\{F - a_j, e_i\} = F - a_j$ then, by Lemma 1, $a_i = e_i$ is still strictly better, given that i's share rises with a_i.

Proof of Lemma 3

(*a*) Because $s_i < 0$, the optimal choice over $[0, F - a_j]$ is 0; if $e_i \le F - a_j$, the upper interval $[F - a_j, e_i]$ is empty and need not be considered.

(*b*) If $e_i > F - a_j$, then 0 must be compared to e_i, which is the maximum on $[F - a_j, e_i]$. i's payoff from $a_i = 0$ is expression (2), while his payoff from $a_i = e_i$ is given by expression (3). A comparison of these payoffs establishes part (*b*) of the Lemma.

Proof of Lemma 4 So long as $s_i \neq 0$ for $i = 1, 2$, then Lemmas 1 to 3 establish that the only possible best responses for i are 0 and e_i.

Proof of Proposition 1

Case (i) follows from Lemma 2: if $s_i > 0$, then for fisher i, e_i is the unique best response to any action chosen by fisher j, and likewise for fisher j, so that (e_1, e_2) is a unique, dominant-strategy equilibrium.

Case (ii) is a consequence of applying Lemma 2 to fisher 1 and Lemma 3 to fisher 2. First note that Lemma 2 implies that e_1 is fisher 1's unique dominant strategy, so there can be no (0, 0) equilibrium. It remains only to show when fisher 2 will choose $a_2 = 0$ or $a_2 = e_2$. The condition that $(G - 1)F \ge Ge_1$ is equivalent to stating that $(e_i/E)G(F - a_j)$ (expression (2)) exceeds $e_iF/(e_i + a_j)$ (expression (3)), where $i = 2$ and $a_1 = e_1$; then fisher 2's best response is $a_2 = 0$, by Lemma 3. Meanwhile, fisher 2 will choose $a_2 = e_2$ iff $(G - 1)F \le Ge_1$.

For case (iii), consider first the (0, 0) equilibrium. Fisher i's best response to $a_j = 0$ is $a_i = 0$ if and only if either $e_i \le F$ (Lemma 3, case (a)) or $e_i > F$ and $(e_i/E)GF \ge F$ (Lemma 3, case (b)). If $e_i \le F$ for $i = 1, 2$, then (given the assumption that $s_i < 0$ for $i = 1, 2$) it follows that (0, 0) is an equilibrium. If, however, for at least one of the fishers j, $e_j > F$, then fisher j's best response to $a_i = 0$ is $a_j = 0$ as long as $(e_j/E)GF \ge F$, which simplifies to $e_j > E/G$; but this is equivalent to the assumed slope condition $s_j < 0$.

The condition for the (e_1, e_2) equilibrium in case (iii) follows from Lemma 3; e_1 is a best response to e_2 if and only if $e_1 > F - e_2$ and

$$\frac{e_1}{E} G(F - e_2) \le \frac{e_1}{E} F$$

(substituting $(a_1, a_2) = (e_1, e_2)$ into expressions (2) and (3) of Lemma 3). This expression simplifies to $G(F - e_2) \le F$, which is equivalent to the second inequality in case (iii) of the Proposition.

It remains to show that there are no equilibria of the form $(e_i, 0)$ in case (iii). If $(e_1, 0)$ is an equilibrium, then Lemma 3 implies that $e_1 > F$ and

$$\frac{e_1}{E}GF \leq \frac{e_1}{e_1}F = F.$$

Consequently, $e_1 \leq E/G$, which, in turn, implies that $s_1 \geq 0$, a contradiction.

Proof of Corollary 2 If the condition of the corollary $(e_i > E/G, \forall i)$ is met, then $s_i < 0, \forall i$, and we are in case (iii) of Proposition 1: $(0,0)$ is always an equilibrium. The commons-dilemma assumption (1), $E \geq GF$, implies that $(G-1)F \leq E$. Meanwhile, the condition in the corollary can be stated as $E < Ge_i$. Therefore $(G-1)F \leq Ge_i$; by case (iii) of the Proposition, full depletion is an equilibrium outcome when $(G-1)F \leq Ge_i$.

Proof of Proposition 2

(*a*) If $(a_1 = a_2 = 0)$ is an equilibrium under e', then under e' the game's parameters correspond to case (iii) of Proposition 1, and from Corollary 1, $e'_i > E/G, \forall i$. e' is a mean-preserving spread of e, so for one fisher (say fisher 2, with no loss of generality), $e'_2 > e_2$, and for the other, $e'_1 < e_1$. Given that $e'_1 < e_1$ and $e'_1 > E/G$, then $e_1 > E/G$. Given that e' is a mean-preserving spread of e and fisher 2's wealth increased, it must have been that $e_2 \geq e_1$. Given that $e_1 > E/G$, it must be that $e_2 > E/G$. Thus $(a_1 = a_2 = 0)$ is an equilibrium under e.

(*b*) If $(a_1 = a_2 = 0)$ is an equilibrium under e, then from Corollary 1, $e_i > E/G, \forall i$. Then redistribute wealth away from one fisher j until $e_j < E/G$; this is a mean-preserving spread of e such that full conservation is no longer an equilibrium.

Proof of Proposition 3 Given $(e_1, e_2) = (E, 0)$, then $s_1 < 0$, $s_2 > 0$, and $(G-1)F > 0$, so that by Proposition 1, $(0, e_2)$ is the unique 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 ϵ, 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

$$\frac{E-\epsilon}{E}G(F-\epsilon) \tag{9}$$

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

$$\frac{E-\epsilon}{E}F. \tag{10}$$

The amount (9) is larger than (10) if

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

Therefore, define

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

(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 Corollary 1, 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.

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

$$\frac{e_j}{E} G\left(F - \sum_{i \in \hat{I}} e_i\right) \tag{11}$$

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

$$\frac{e_j}{E} G\left(F - \sum_{i \in \hat{I}} e_i - e_j\right) + e_j. \tag{12}$$

Now (11) is at least as large as (12) if and only if $e_j \geq E/G$. By similar logic, if a fisher k nominally in $\hat{I}$ is unilaterally 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 $k \in \bar{I}$, then fisher k will always conserve regardless of the choices made by other fishers. To see this, consider fisher k's choice. Say that all other fishers fish to capacity in period 1, and that $E_{-k} \equiv \sum_{i \neq k} e_i$ is the sum of wealth held by all other fishers. Furthermore, assume that $E_{-k} < F$. Then if fisher k chooses to conserve, his payoff is

$$\frac{e_k}{E} G(F - E_{-k}) \tag{13}$$

while if fisher k fishes to capacity in period 1, his payoff is $(e_k/E)F$. Now (13) is at least as large as $(e_k/E)F$ if

$$E_{-k} \leq \frac{F(G-1)}{G} \tag{14}$$

now since $e_k = E - E_{-k}$, (14) is equivalent to

$$e_k = E - E_{-k} \geq E - \frac{F(G-1)}{G}. \tag{15}$$

But (15) always holds by fisher k's inclusion in $\bar{I}$. Thus for any fisher with wealth sufficiently great to be in $\bar{I}$ conservation is a dominant strategy.

Now consider an unequalising wealth 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; fisher k waits to deploy his wealth, including the transfer from fisher j, until the second period. Thus period-1 fishing is strictly decreased and equilibrium efficiency is strictly increased.

We must also consider unequalising transfers $j \in J$ to fishers k not in $\bar{I}$. If $k \in J$, then $e_k < E/G$. After the transfer $\eta > 0$, fisher j's period-1 fishing is decreased by η. If

$e_k + \eta \geq E/G$, then fisher k could choose to conserve and equilibrium efficiency would strictly increase. If $e_k + \eta < E/G$, fisher k will increase his period-1 fishing by η and aggregate period-1 fishing (and thus equilibrium efficiency) is unchanged. Suppose finally that fisher k is neither in J nor $\bar{I}$. As before, fisher j will decrease his period-1 fishing by η after the transfer. If fisher k conserves in equilibrium before the transfer, he will continue to do so after the transfer; aggregate period-1 fishing is decreased by η. Even if fisher k did not conserve before the transfer, he could now find it optimal to do so, and equilibrium efficiency would increase. If fisher k did not conserve before the transfer, and still chooses not to after the transfer, his increased fishing exactly offsets fisher j's reduction and equilibrium efficiency is unchanged.

Proof of Proposition 7 Assumptions (5) and (6) together imply that condition (4) is satisfied as an equality for fisher i at two points: where $e_i = 0$, and where $e_i = e^\star$ for some $e^\star > 0$. Moreover, for values of wealth such that $0 < e_i < e^\star$, condition (4) *does not hold, while for values of wealth such that* $e_i \geq e^\star$, *it does. Consider two cases.*

(i) Full conservation is an equilibrium outcome under e. Then it must be that both fishers have wealth greater than $e^\star$. Then transfer, from one fisher to another, an amount such that the first's wealth is now below $e^\star$. Then, for the first fisher, condition (4) no longer holds, and conservation is no longer an equilibrium outcome.

(ii) Full conservation is not an equilibrium under e. Then it must be that at least one fisher's wealth lies below $e^\star$. 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 We will prove the contrapositive of the proposition: that is, we will show that, if under perfect inequality, full conservation is not an equilibrium outcome, then there exists no other wealth distribution with $e_i > 0, \forall i$ 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 possible values of e_i, $i = 1, 2$. In this case, both fishers always prefer the exit strategy at all positive values 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

$$\frac{e_i}{E} GF \geq \psi(e_i) + \min\{e_i, F\}. \tag{16}$$

Say that $\underline{E}$ is the lowest value of wealth for which (16) is true, and $\bar{e}$ is the highest level of wealth for which (16) is true. Then if under the distribution $e = (s, s)$, full conservation is not an equilibrium outcome, it must be either that $s < \underline{E}$ or $s > \bar{e}$. These are the two remaining cases we must 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, the latter's wealth could eventually exceed $\underline{E}$, so that fisher 2 would be willing to conserve, conditional on fisher 1's conservation. But fisher 1's wealth will always be less than $\underline{E}$, and given the restriction that both fisher wealth always be positive, fisher 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 fisher 2, the exit strategy will continue to dominate conservation for fisher 2, regardless of fisher 1's strategy. Thus under no mean-preserving spreads of e is conservation an equilibrium outcome.

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