Cooperation and Club Goods: Fisheries Management in the Spirit of Elinor Ostrom

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ABSTRACT

The challenge of achieving stable fisheries cooperative arrangements worldwide, at both the international and the domestic level, is increasingly important, but most game theoretic analyses of such arrangements have produced pessimistic results. Yet Elinor Ostrom and colleagues, emphasizing what might be termed social capital, refute these pessimistic results, at least at the domestic level. To date, there has been no effective way of incorporating such social capital into game theoretic models of fisheries. Focusing on the domestic level, this paper attempts to do just that. In so doing, the paper employs the concept of "club goods," where a club good is nonrivalrous, but excludable. The paper, commencing with a model involving a repeated game with trigger strategies, is extended to include the club good, with dramatic consequences for the stability of the game. Elinor Ostrom and colleagues stand vindicated. Extending this analysis to the international level is the next challenge.

Key words: Club good, cooperation, fisheries management, game theory.
JEL codes: C71, C73, D71, Q22.

INTRODUCTION

The importance of achieving stable cooperative fisheries management arrangements at the international level has long been recognized, and continues to be emphasized (e.g., Kwon 2006; Bailey, Sumaila, and Lindroos 2010; Miller and Nkuiya 2016; Bediako and Nkuiya 2022).[1] More recently, there has been increasing recognition of the high importance of such cooperative fisheries management arrangements at the domestic level (within the exclusive economic zone [EEZ]; e.g., Sumaila 2013; Grønbæk et al. 2020). This article will address the question of the prospects of achieving stable cooperative resource management arrangements at this second level.

One of the most effective game theoretic tools for analyzing cooperative fisheries management arrangements at either level has been found to consist of partition function games (Kronbak and Lindroos 2006; Pintassilgo et al. 2010). The partition function games enable us to deal with positive externalities in coalition formation, thereby highlighting the problem of free riding (Yi 2003).

In their static, steady-state form, the predictions of these partition function game models are not encouraging. Free riding is seen to be an intractable problem, unless the number of players is small. The introduction of asymmetries increases the scope for stable cooperative arrangements,

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1. There is also a relevant, useful reference from the pollution literature that deserves mention, namely Tarui et al. (2008).

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but only modestly (Pintassilgo et al. 2010). Thus, the prospects for achieving stable cooperative domestic fisheries management regimes appear, on the face of it, to be bleak.

Yet, Elinor Ostrom, as far back as 2000 (Ostrom 2000), has argued that such pessimism is unwarranted. Empirical evidence, Ostrom maintains (Ostrom 2000), demonstrates that stable cooperative management regimes of domestic common-property resources, certainly including fisheries, are far more common than the theory would predict. For empirical examples of stable cooperative management regimes of domestic common-property resources, pertaining to fisheries, one cannot do better than to turn to the chapter by Edella Schlager on domestic fisheries management (Schlager 1994) in the book *Rules, Games, and Common-Pool Resources*, by Ostrom, Gardner, and Walker (1994). Schlager presents an exhaustive review of cooperative domestic fisheries management arrangements in several continents.

If steady-state game theoretic models yield unduly pessimistic predictions with respect to domestic cooperative fisheries management arrangements, then the obvious question is whether dynamic game theoretic models will yield predictions that are more in keeping the empirical observations cited by Ostrom and her colleagues. We perceive two approaches to addressing this question. The first, origins of which in fact go back to Kaitala and Pohjola (1988) and Hannesson (1997), later followed by Polasky et al. (2006), is to turn to repeated games with trigger strategies. Free riding, upon detection, leads to a reversion to noncooperation by all, either forever (Hannesson 1997) or temporarily (Polasky et al. 2006). In either case, this is a form of noncooperative game, but in which it can be demonstrated that a first best solution can be supported as a subgame perfect Nash equilibrium. The achievement of the first best solution depends upon several factors, particularly the discount rate and the number of players. The predictions, while certainly better than those of the steady-state game theoretic models, are, in fact, not all that encouraging.

The second approach, which draws upon some of the empirical observations of Ostrom and colleagues (Ostrom 2000), is to incorporate into the theory what might be termed social capital in the repeated games. We think of the work of Osés-Eraso and Viladrich-Grau (2007, 394) in which "social approval of cooperating agents by other cooperating agents works as reward mechanism." Needless to add, free riding, upon detection, results in loss of this social approval and all that that implies.

Though both approaches use the repeated game setup, there is an important difference between the two approaches. In the first approach, as has been noted by others in different contexts (e.g., Nordhaus 2015), invoking the threat involves inflicting harm, not only upon the deviators, but upon the punishers as well. The punishers are punished. The reversion to noncooperation hurts all, which leads in turn to questions about the credibility of the threat. In the second approach, invoking the threat leaves the punishers to a large extent unscathed as they will remain in a coalition playing a Nash game against the deviator.

In this paper, we focus upon the second approach, and in so doing focus particularly upon the concept of "club goods." To be reminded, while a public good is both non-rivalrous and non-excludable, a club good is non-rivalrous, but excludable. The club good, which may well be less than perfect, will include all the benefits arising from belonging to the club, such as sharing of information about the location and the abundance of the stock, and importantly good social standing. Those found guilty of transgression are punished by being denied some or all of the club benefits. It will be seen, with inspiration coming from Heintzelman, Salant, and Schott (2009), that punishments imposed by the club exclusion can be captured simply, neatly, and elegantly by a scale parameter, which will affect the penalty function.

The club good concept has in fact been applied in some detail in the pollution literature, with the best example being provided by Nordhaus (2015). Nordhaus is concerned with global climate agreements, with the participating players in the climate cooperative game forming the club, who then stand ready to impose penalties on noncooperating players. He makes a clear distinction between internal penalties, which are related to the payoffs of the original cooperative game, and external penalties, which are unrelated to those payoffs. Only external penalties in which one can have confidence that they will hurt those not cooperating while leaving those cooperating unhurt will be effective, or so argues Nordhaus (2015). Nordhaus does not, it is to be noted, apply a formal model.

In what follows, the club good penalties are, using Nordhaus's definition, strictly internal in nature. Nonetheless, it can be demonstrated that these internal penalties can in fact be designed in such a manner that they impose harm upon the defectors, while actually benefiting those who resist the temptation to defect.

Let us consider a simple illustrative example, one that is provided to us by the detailed study of Salagrama (2006) of two fishing villages in the state of Andhra Pradesh in India. The community-based fisheries management schemes in the villages have proven to be very successful over time, and they have proven to be so in the face of negative support from government fisheries regulators, who are at best indifferent, and at worst hostile.

Critical to the success of the community-based fisheries management schemes is the fishermen caste, the Caste Panchayat, which governs the life of the villages, certainly including fisheries. The Caste Panchayat is the club. There exists in each village a Caste Council, made up of elders. Those who are suspected of violating the rules governing fisheries are brought before the Council. The transgressors who are found guilty face punishments ranging from fines to being ostracized, resulting in banishment from the relevant fisheries, and banishment from village life in general (Salagrama 2006). The penalties are internal to the club. They impose harm, costs, upon the trangressors, the defectors, but impose no harm upon the righteous. Indeed, in the case of fines, the proceeds can be directly used for the benefit of the non-defectors.

We proceed as follows. We commence by establishing what we shall term a baseline fishery model of symmetric players, playing a repeated partition function game, with trigger strategies à la Hannesson (1997) and Polasky et al. (2006). We then present an extended version of the model by introducing the club good. The consequence will be that the game will be symmetric, unless there is a deviator that is detected. If this occurs, the game will then be asymmetric for the deviator. The asymmetry, it will be seen, greatly enhances the stability of the game, as will be illustrated with the aid of a numerical example.

THE MODEL

We assume a set of n players, P, which are ex ante symmetric, $P = \{1, 2, \ldots, n\}$, that in turn exploit a common-pool resource. In particular, we are considering a fishery in which players can form coalitions, S. The appropriate framework for mapping the coalition structure C into a vector of values for each coalition in the coalition structure is the partition function approach originally introduced in 1963 by Thrall and Lucas. The partition game, $\Gamma(P, \Pi)$, is defined by the set of players, P, and the partition function Π.

A coalition structure, $C = \{S_1, S_2, \ldots, S_z\}$, is defined by a partition of the set of players, $P = \{1, 2, \ldots, n\}$: $\cup_{k=1}^{z} S_k = P$ and $S_i \cap S_j = \varnothing, \forall i, j \in \{1, 2, \ldots, z\} \wedge i \neq j$, z is the number of coalitions in the coalitions structure. This defines a coalition structure as a series of coalitions, where all players are members of exactly one coalition. A common assumption in partition fishery games, which eases the modeling, is that all players are ex ante symmetric. Under this assumption, it is sufficient to identify a coalition by its size (Yi 2003). Hence, $C = \{S_1, S_2, \dots, S_z\}$ can be written as $C = \{n_1, n_2, \dots, n_z\}$, where n_i is the size of coalition S_i. Note that a coalition can consist of a single player, a singleton.

The partition function, $\Pi(n_i; C)$, maps a vector of payoff values to each coalition structure. The per-member partition function, $\pi(n_i; C)$, yields the payoff of a coalition of size n_i in the coalition structure, C. The per-member partition function can be used in the case of symmetric players to describe the payoff to a member of a size n_i coalition in the specific coalition.

A FISHERY BASELINE MODEL

We turn now to what we term our baseline fishery model, which to repeat is one consisting of symmetric players, playing a repeated partition function game, with trigger strategies. The objective function for each coalition is to maximize the discounted values of the payoff of the coalition. The model is built upon the classical Gordon-Schaefer harvest model with identical and constant unit costs per effort and a constant price (Gordon 1954). The dynamics of the fishery is defined by the following equations:

$$\Delta X_t = G(X_t) - \sum_{i=1}^{z} H_{t,i}, \tag{1}$$

$$G(X_t) = rX_t\left(1 - \frac{X_t}{k}\right), \tag{2}$$

$$H_{t,i} = qE_{t,i}X_t, \tag{3}$$

where t is the time indicator, X represents the biomass of fish stock, ΔX_t is the change of the biomass in time, and $G(X)$ is the growth function assumed to follow the logistic growth as described in equation 2. H_i is the harvest of coalition S_i, z is the number of coalitions, and R and k are biological parameters, the intrinsic growth rate and the carrying capacity (i.e., the maximum size of X), respectively. The harvest of coalition S_i is assumed to be linear in effort, E_i, and the biomass. The term q, a constant, is the catchability coefficient, $0 < q$.

Based on a static game optimized with resepct to effort, this procures the steady-state equilibrium for the stock. This is derived through the relationship of biomass and harvest in equations 1–3; we define the objective function of our repeated game for any coalition S_i as

$$\begin{aligned} \max_{E_i}\sum_{t=0}^{\infty}\delta^t\pi(n_i; C) &= \sum_{t=0}^{\infty}\delta^t(pH_i(E_i, X) - cE_i), \\ \text{s.t. } X &= \frac{k}{r}\left(r - q\sum_{i=1}^{z}E_i\right), \end{aligned} \tag{4}$$

where z is the number of coalitions in the game; c, a constant, is the unit cost of fishing effort, E; and p, a constant, is the price of harvested fish. E_i does not directly depend on n_i; however, the optimal E_i effort chosen by coalition S_i does depend on the size of n_i. The model is a static repeated game where the steady-state eguilibrium is derived, thus limiting the stock to always be in equilibrium.[2] The link between periods is provided by the discount factor, denoted by δ. We

2. This assumption of turning the game into a sequence of static games over time does, let us admit, place some limitations on the applicability of the model.

have $\delta = 1/(1 + \rho)$, where ρ is the per period discount rate. The model is an infinite time horizon model as in Hannesson (1997). For the remainder of the paper, we apply a single coalition open membership game.

According to the literature, if a single player deviates from the optimal solution, this player will achieve higher profits in the periods for which the deviation is not detected. In a game with positive externalities, which is the case in fishery games (Pintassilgo 2003), this profit will be much higher than the profits of the standard noncooperative game. Since the players are symmetric and move simultaneously, it will be the case that, while the deviator remains undetected, a coalition and one free rider will, from a modeling perspective, act as a two-player Nash game. The free rider, which we shall denote as j because players are symmetric, will thus enjoy the same economic benefits as the coalition of $(n - 1)$ players—very profitable indeed for the undetected free rider.

A deviating player will be detected after a number of periods, say τ. Then, after the $(t + \tau)^{\text{th}}$ period, the other players respond to the deviation. This could be either as a *trigger strategy*, where detected deviation triggers a switch to noncooperation forever after, or as a temporary and less harsh *tit-for-tat* strategy, where the strategy to begin with is cooperation and for the subsequent period adoption of the strategy of the opponent (in this case the deviator). In this model, the classic trigger strategy is assumed to be adopted and, as in Hannesson (1997), it is assumed that deviation is detected after one period and, hence, $\tau = 1$. It is a matter for discussion whether a period of detection longer than one period can be realistic in a model where players make harvest decisions simultaneously and information is symmetric and perfect.

When the deviator, j, is detected the trigger strategy comes into play and the grand coalition disintegrates into full noncooperation. The deviator will thereafter enjoy the minimax value, v_j, which is the lowest possible outcome that the other $(n - 1)$ players can impose upon player j, through the reaction function. Player j always maximizes her own best response function, but this function depends on the actions of the other players (choice of effort) and, therefore, the other players can hold a minimum value on player j, which we shall define as player j's reservation utility. The stage game payoff is generated by the mutual best responses in a noncooperative game.

Player j's reservation utility v_j is that player's payoff arising from the noncooperative Nash equilibrium. In the general case there could be more than one Nash equilibrium, and then we would take the minimum of these; this corresponds to the minimax value for player j. The reservation utility will, for later purposes, be used as the worst possible equilibrium that the player can face. Define the minimax value as

$$v_j = \min_{E_{-j}} \left[\max_{E_j} \pi\left(E_j, E_{-j}\right) \right],$$

where E_{-j} is the effort of the coalition of $(n - 1)$ players without the would-be deviator, and E_j is the effort of the would-be deviator. The would-be deviator, j, has to balance off the short-term gains, while undetected, against the losses following detection, where the "losses" are seen to be the difference between the full cooperation payoff to j, and the payoff to j arising from full noncooperation. These losses would go on until the end of time. The would-be deviator's decision to deviate or not to deviate will, of course, be dependent upon the discount factor. The famous *folk theorem* states that in such a game, a cooperative, first best outcome can be supported as a subgame perfect Nash equilibrium, if the discount factor is large enough (Fudenberg and Tirole

Table 1. Fishing Effort Levels in Different Scenarios of Cooperation: The Baseline Model

Scenario of Cooperation	Effort	Note
Full cooperation	$E^* = \frac{r}{2q}(1-b)$	Each player plays $1/n^{\text{th}}$ of this effort
Deviation by 1 singleton, j—not detected	$E_j^d = E^*(1 - \frac{1}{2}\frac{n-1}{n})$	Remaining members of the coalition play above effort
Deviation by 1 singleton, j—detected, reversion to full noncooperation	$E^{nc} = \frac{r}{(n+1)q}(1-b)$	Effort per player

Note: E^* is the optimal effort level of the grand coalition (i.e., $z = 1$) and E^{nc} is the individual effort in a non-cooperative game (i.e., $z = n$).

1991; Hannesson 1997). If the discount factor were equal to 1 ($\rho = 0$), then the first best outcome would be assured, or so it would seem. In any event, denote the minimum size discount factor required to support a first best outcome as $\underline{\delta}$.

We could, of course, allow for the possibility of several would-be deviators. For the sake of simplicity and clarity, however, we shall assume in this section, and in the sections to follow, that there is but one would-be deviator. If the would-be deviator becomes an actual deviator, the actual deviator would, by definition, be a singleton.

Next, for analytical purposes and for purposes of future comparison, we derive the one-shot fishing effort profiles from equations 1–3 for the different scenarios of cooperation described. These scenarios are full cooperation, deviation by one singleton not detected, and deviation by one singleton detected, leading to full noncooperation.[3] Optimal efforts are derived in combination with optimal stock size, as the derivation is based upon the maximization of the coalition objective function equation 4; that is, the equality $X = \frac{k}{r}(r - q\Sigma_{i=1}^{z} E_i)$ must hold. Therefore, the optimal level of effort is inversely related to the optimal stock size, X. Consider now table 1, where the parameter, b, is the so-called inverse efficiency parameter, $b = c/(pqk)$.[4] What table 1 reemphasizes is (1) that under full cooperation all players enjoy equal economic returns from the fishery, and (2) that the deviator, while undetected, enjoys exceptional economic returns.[5]

When the deviator is detected, the non-deviators have but one choice, to pull the trigger or not to pull the trigger. If the trigger is pulled—we assume that it will be—there will be a reversion to full noncooperation. With the trigger being pulled, the post-detection rates of fishing effort and the net economic returns per period will be the same for all. The deviator is punished, but so are the virtuous, the non-deviators—what we might term the curse of symmetry. Further, it goes without saying that the outcome of the full noncooperative game is wholly beyond the control of the non-deviators. In any event, this then is our baseline model, following Hannesson (1997) and Polasky et al. (2006), which was originally defined by Friedman (1971) in a seminal paper of noncooperative equilibrium in supergames.

3. The full cooperation effort level equation is derived from the solution to a cooperative game (same as the sole owner optimum; Scott 1955), and the full noncooperative effort level equation is derived from the solution to an n player noncooperative game, both based on equation 4. See Grønbæk et al. (2020, chap. 3). The effort by the deviator when he/she is not detected is the optimal effort level for this player given that the remainder of $(n - 1)$ players employ their share of the full cooperation effort.

4. In this model, the unit cost of harvesting $c(X)$ is equal to $c/(qX)$. The larger is X, the lower is the unit cost of harvesting. If $b = 1$, it means, as the reader can easily determine, that when X is at its maximum size ($X = k$), we shall have $p - c(X) = 0$. As can be seen in table 1, if $b = 1$, E^*, both under full cooperation and under full noncooperation, will go to zero.

5. Consider the following simple example. Suppose, for the sake of argument, that we have a game with 10 players, for example, $n = 10$ players. If the would-be deviator does not deviate, its effort level will be equal to $0.1E^*$. If it does deviate, and is not detected, its effort level will, as the reader can easily verify, be equal to $0.55E^*$.

THE CLUB GOOD INTRODUCED

We now extend the fishery baseline model by introducing a club good. A club good, let us recall, is non-rivalrous, but is excludable, and is seen to include all benefits arising from the club, such as sharing of information and good social standing. The grand coalition is to be seen as the club. Those excluded from the club are punished by being denied the benefits of the club. In the baseline model, the club benefits are assumed not to exist, or are simply ignored. To capture the elements of the club good, we introduce a scale parameter inspired by Heintzelman, Salant, and Schott (2009). A somewhat similar idea is also discussed by Holmström and Tirole (1989), who discuss the problem of sharing benefits when more workers are required for producing the output.

Define the scale parameter as $\beta =]0;1[$. We continue to assume constant unit cost of fishing effort. Under full cooperation, the unit cost of fishing effort for every player is c as in the baseline model. This will also hold true if there is a deviator that goes undetected. If, however, the deviator is detected, the deviator is punished by the club, and its unit fishing effort cost is deemed to be c/β, with $\beta < 1$. Thus, the penalty, the punishment, imposed by the club is seen as being the equivalent of higher fishing effort costs for the deviator. The lower is β, the more severe are the consequences of the punishment by the club.[6] Obviously, non-punishment by the club implies $\beta = 1$. In the baseline model, with club good benefits assumed to be nonexistent or ignored, we thus have implicitly $\beta = 1$ throughout. Thus, the parameter β can be viewed as a measure of the strength of the club good. If β is close to 1, the cosequences of banishment from the club are minor indeed, whereas if β is close to 0, the consequences of such banishment are severe.

In the extended model, the players are symmetric under full cooperation, under full noncooperation, and when there is a deviator that goes undetected. When there is a deviator that is detected, then, as it will be seen, the players become asymmetric. This asymmetry, as we have indicated, proves to be crucial. With the complications introduced by the club good, we have to be more precise about our definitions of scenarios of cooperation than we were in the fishery baseline model. We attempt to achieve this greater degree of precision in table 2.

OBJECTIVE FUNCTION: THE CLUB GOOD INCLUDED

With the club good introduced and the resultant scale parameter being defined, we must now revise the objective function for coalition S_i, which will vary for the different scenarios. We have equation 5, which the reader will want to compare with equation 4:

$$\begin{aligned} \max_{E_i} \sum_{t=0}^{\infty} \delta^t \pi(n_i; C) &= \sum_{t=0}^{\infty} \delta^t \left(pH_i(E_i, X) - \frac{c}{\beta} E_i \right), \\ \text{s.t. } X &= \frac{k}{r}\left(r - q\sum_{i=1}^{z} E_i \right), \end{aligned} \tag{5}$$

where z is the number of coalitions in the game, and where table 2 defines the different cases of β for the different scenarios of cooperation and deviation. We continue to have a repeated static game in steady-state equilibrium, which allows for the achieving of a solution to the game, ensuring a subgame perfect Nash equilibrium.

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6. Return to the simple illustrative example set forth in the Introduction of community-based fisheries management schemes in the Indian state of Andhra Pradesh, in which punishments imposed upon fishers violating the rules range from fines to banishment from the relevant fisheries. The fines represent an explicit increase in costs to guilty fishers. Banishment from the fisheries can be seen as an implicit cost increase, sending the costs of fishing to infinity (i.e., $\beta = 0$), or at least to a level that makes fishing financially infeasible.

Table 2. Definition of Scenarios of Cooperation: The Club Good Case

Scenarios of Cooperation	Strategy	β	Unit Cost of Fishing Effort
Full cooperation	Cooperative strategy	1	c for everyone
Deviation—not detected	Coalition plays cooperative strategy, deviator plays best response to this	1	c for everyone
Deviation—detected	Nash game between coalition and deviator	1	c for coalition members
		]0; 1[	c/β for deviator
Noncooperation	Nash game among all players	]0; 1[	c/β for everyone

We now complement table 1 with table 3, which gives us the different levels of fishing effort in the different scenarios of cooperation, with the club good included. The effort levels for detected deviator, j, and for the remaining coalition in table 3 are derived from the solving of the general two-player asymmetric noncooperative game based on equation 5. See Lemma 1 to follow. Deviation by the singleton player is very profitable for the deviator, if not detected. As the reader can readily verify, the deviator's effort level is higher than it would be if it did not deviate,[7] and it continues to enjoy all of the benefits of the club, that is, for the deviator $\beta = 1$.

What if the deviator is detected? Consider Lemma 1.

Lemma 1. Relation of effort levels if the deviating agent is detected in the club good case. When a deviating agent is excluded from the club good, the game becomes an asymmetric two-player game with a coalition and a deviator. The deviator applies the effort level $E_j^d = r/(3q)(1 + b(1 - 2 / \beta))$ after detection of the deviation, and the remaining members of the coalition jointly apply the effort level $E^c = r/(3q)(1 + b(1/\beta - 2))$, where each player in the coalition plays $1/(n-1)^{\text{th}}$ of this effort. The effort of the remaining coalition is larger than the effort of the deviating agent.

Proof. From table 3, we have the effort levels, which follow from optimization. Since effort levels for the subcoalition and the deviator are not identical, the game is assymetric. We provide contradictory evidence by assuming $E_j^d \geq E^c$. Then we have the following:

$$E_j^d = \frac{r}{3q}\left(1 + b\left(1 - \frac{2}{\beta}\right)\right) \geq \frac{r}{3q}\left(1 + b\left(\frac{1}{\beta} - 2\right)\right) = E^c.$$

This implies, given that both r and q are positive,

$$\left(1 + b\left(1 - \frac{2}{\beta}\right)\right) \geq \left(1 + b\left(\frac{1}{\beta} - 2\right)\right),$$

which again implies

$$b\left(1 - \frac{2}{\beta}\right) \geq b\left(\frac{1}{\beta} - 2\right).$$

Given that the inverse efficiency parameter, b, is positive we have

$$1 - \frac{2}{\beta} \geq \frac{1}{\beta} - 2$$

7. See footnote 4.

Table 3. Effort Levels in Different Scenarios of Cooperation: The Club Good Case

Scenario of Cooperation	Effort	Note
Full cooperation	$E^{\star} = \frac{r}{2q}(1-b)$	Each player plays $1/n^{\text{th}}$ of this effort
Deviation by 1 singleton, j—not detected	$E_j^d = E^{\star}(1-\frac{1}{2}\frac{n-1}{n})$	Remaining members of the coalition play effort above
Deviation by 1 singleton, j—detected	$E_j^d = \frac{r}{3q}(1+b(1-\frac{2}{\beta}))$	Each player in the coalition plays $\frac{1}{n-1}^{\text{th}}$ of the coalition's effort
	$E^c = \frac{r}{3q}(1+b(\frac{1}{\beta}-2))$	
Full noncooperation	$E^{nc} = \frac{r}{(n+1)q}(1-\frac{b}{\beta})$	Effort per player

or

$$3 \geq \frac{3}{\beta},$$

which corresponds to the following, as β is positive:

$$\beta \geq 1,$$

which cannot be true, as by definition $\beta =]0; 1[$. Thus, it follows that $E_j^d < E^c$.

We next turn to the minimax value of the detected deviator. The minimax value was defined in the fishery baseline case, in which the club good was nonexistent. With the club good present, we redefine the minimax value as

$$\underline{\widehat{v_l}} = \min_{E_{-j}}\left[\max_{E_j}\pi_j\left(E_j, E_{-j}, \beta\right)\right]. \tag{6}$$

We keep the definition of $\underline{\delta}$ as the minimum discount factor, for which the folk theorem holds true in the fishery baseline model (i.e., $\beta = 1$ throughout). We now need to demonstrate that, in the club good case, with the possibility of $\beta < 1$ introduced, in a given situation in which deviation and cooperation are equally preferred cooperation will be likely for higher levels of discount rates.[8] We undertake the required demonstration in Proposition 1.

Proposition 1. Let the game, $\Pi(n_i; C; \beta)$, be finite in the number of players with simultaneous moves. For every feasible payoff vector, v, with $v_j > \underline{\widehat{v_i}}\ \forall\ j \in P$ and $\forall\ \beta \in]0, \bar{\beta}[\ \ \exists\ \underline{\hat{\delta}} < \underline{\delta} < 1$ such that $\forall\ \delta \in]\underline{\hat{\delta}}, 1[$, there is a subgame perfect Nash equilibrium of $\Pi(n_i; C; \beta)$ with payoffs, v.

Proof. According to the folk theorem, we know that $\underline{\delta}$ exists corresponding to the game $\Pi(n_i; C; 1)$. We now need to show that as β is introduced, the game $\Pi(n_i; C; \beta)$ implies a new value of the discount factor, $\underline{\hat{\delta}}$, which satisfies the folk theorem and for which $\underline{\hat{\delta}} < \underline{\delta}$. From equation 6 and the information about the first-order derivative of the profit with respect to β (see equation 5), we know that $\underline{\widehat{v_i}} < \underline{v_j}$, where $\underline{v_j}$ refers to the minimax value from the original game without a club good. Following the folk theorem, for deviation not to be preferable when β has been introduced, the following expression must be true:

8. We interpret the strategy to be "preferable to the reservation value," as presented in Proposition 1 as the cooperative strategy. In principle, it can be any strategy as long as the individual payoff exceeds the minmax values. Beta can also be connected to this; for example, if we do not follow the agreed strategy, then information vanishes, and it becomes costlier to exploit the common-pool resource.

$$\pi_j\left(e_j, e_{-j}\right) + \frac{\delta}{1-\delta}\underline{\widehat{v_i}} < \frac{1}{1-\delta}v_j,$$

$$\delta > \frac{\pi_j\left(e_j, e_{-j}\right) - v_j}{\pi_j\left(e_j, e_{-j}\right) - \underline{\widehat{v_i}}}.$$

We know that $v_j > \underline{\widehat{v_i}}$ so that $(\pi_j(e_j, e_{-j}) - v_j) / (\pi_j(e_j, e_{-j}) - \underline{\widehat{v_i}}) < 1$. Let us call $\underline{\widehat{\delta_i}} = (\pi_j(e_j, e_{-j}) - v_j) / (\pi_j(e_j, e_{-j}) - \underline{\widehat{v_i}})$. A player will not deviate as long as δ for which $\underline{\widehat{\delta_i}} < \delta < 1$. This holds true for all players in the game, and since $\underline{\widehat{v_i}} < \underline{v_j}$ for all players it follows that $\underline{\hat{\delta}} < \underline{\delta}$. The fact that the game is subgame perfect Nash equilibrium follows directly from the proof of the folk theorem.

With Proposition 1 in hand, let us observe the following, continuing to focus on the deviator detected. Compare table 3 with table 1. In the baseline case (trigger strategy), the detection of the deviator leads to the punishment of the deviator, accompanied by the equal punishment of the non-deviators—the curse of symmetry. In the club good case, the detection of the deviator does not lead to equal punishment for the deviator and non-deviators. The curse of symmetry is lifted. Indeed, in the club good case, if the β is far enough below 1, the virtuous, the non-deviators, will not suffer at all in punishing the deviator.

For example, suppose that β is given to us by the following equation: $\beta = 2/(1 + 1/b)$. Turn to the effort equation of the deviator detected in table 3. It can then be seen that, if β were so given, we would have $b(1/\beta - 2) = -1$, with the consequence that the deviator's rate of fishing effort would go to zero. In other words, the detected deviator's costs would be so high that it would be forced out of the fishery. For the non-deviators, the global net economic returns from the fishery would be the same as under full cooperation, but these economic returns would be divided among $n - 1$ players, rather than n players. The non-deviators, far from being punished, would be rewarded.[9]

Next let us note the following critical fact. In the fishery baseline model, all of the parameters, such as ρ, are exogenous to the model. In the extended model, with the club good, there is a key parameter β, which is to be seen as endogenous to the model. Similar to the discount rate in the baseline model, it is possible to determine a β where the game switches from being a cooperative game to a noncooperative one. This is illustrated in the numerical example to follow.

The design of the club good is within the power of the members of the coalition.[10] They can determine, or at least attempt to determine, the harshness of the punishment inflicted upon detected deviators, that is, they can determine (attempt to determine) how far β falls below 1. That power, in turn, gives the coalition power over the minimax value of the detected deviator and over the minimum discount factor required to ensure cooperation.

This then raises the question of how powerful the club good must be, how harsh the punishment must be upon a detected deviator (how far below 1 β must be), in order to achieve the desired stable cooperation. Given p, c, r, and k, this will depend upon both the number of players and the discount rate. We illustrate all of this with the aid of the following numerical example. The example will also serve to demonstrate the effect of introducing a club good, that is, of having a $\beta < 1$.

9. The establishment of the club is exogenous to this model, but one can, nonetheless, ask why the club is formed in the first place. We cannot provide a full answer, but suggest that first the fishers realize they will benefit from cooperation and realize further that they will do so only if they effectively curb free riding. They are intelligent enough to realize as well that implementing a trigger type strategy is a grossly inferior way of dealing with free riding, and thus turn to what we are calling club goods—hence the club.

10. Return once more to our illustrative example from India set forth in the Introduction, and the all-important fisher caste, the Caste Panchayat. The Caste Council has the power to vary the severity of the punishment, that is, it has the power to set β.

HYPOTHETICAL NUMERICAL EXAMPLE

In the numerical example to follow, we illustrate the size of the parameter, β, required to ensure effective cooperative mangament, first with respect to the number of players in the game, and second with respect to the size of the discount rate. For the numerical example, we apply the equations from table 3 corresponding to cooperation, deviation, and what comes afterwards. In the first period all players willingly cooperate with the exception of one, which is considering the possibility of deviation. Once again, the prospective deviator must compare the gains from deviation, assumed to last over one period, with the losses following detection.

To determine this, we apply the cooperative effort and the effort from deviation for one player, one would-be deviator. Based on these effort levels, we compute the payoffs. In the second period, after detection, and thereafter, the game switches to partial cooperation, where the remaining players in the grand coalition continue to cooperate. There is thus a noncooperative game between the coalition with $(n - 1)$ players and the deviator, and the deviator is faced with a $\beta <$ 1. The potential deviator compares the payoff to it from this course of action to the payoff it would receive if it remained in the grand coalition, a member of good standing in the club. The prospective deviator then makes its choice.

In the example, we assume a game with eight players, one free rider, and a duration, a time horizon, of 30 periods. This information and the parameter values of the game are summarized in table 4. To develop the example, we introduce the scale parameter, β, and determine the critical values of this parameter needed to ensure the stability of the coalition. We do this by examining the stability of the grand coalition for different values of β, first with respect to the the number of players, and second with respect to different discount rates.

Consider now figure 1. On the left-hand side, we assume that $\rho = 0.10$ throughout. We then ask what β must be to ensure stability, given different numbers of players, n, in the grand coalition. On the right-hand side, we assume that $n = 8$ throughout, and then ask what β must be to ensure stability, given different values of ρ.

The left-hand side of figure 1 illustrates the effect of the scale parameter, β, on the maximum number of players compatible with stability of the coalition. As n is an integer, it is a stepwise graph where points are connected. The shaded gray area is the combination of the number of players and the size of the scale parameters, where it is possible to sustain a cooperative solution. We see that for high values of β, equal to or close to 1, the number of players compatible with stability is low. This is consistent with the results that we have from previous trigger models where cooperation is sustained with only two players. Turning this around, it can be seen that if the number of players is low, one can be very relaxed about creating an effective club good.

Such a relaxed attitude will not do if the number of players is other than low. The greater the number of players, the lower β must be. That being said, note that with lower values of β, the number of players compatible with stability increases exponentially, and that at some low value

Table 4. Game and Parameters for Numerical Example

$n = 8$	$t = 30$	$p = 1$	$r = 0.8$	$k = 100$	$q = 0.5$	$c = 5$	$\rho = 0.1$

Note: The term n is the number of players, t is the time horizon of the game, p is the price per unit harvested, r is the intrinsic growth of the stock, k is the carrying capacity of the stock, q is the catchability coefficient, c is the cost per unit of effort, and ρ is the discount rate.

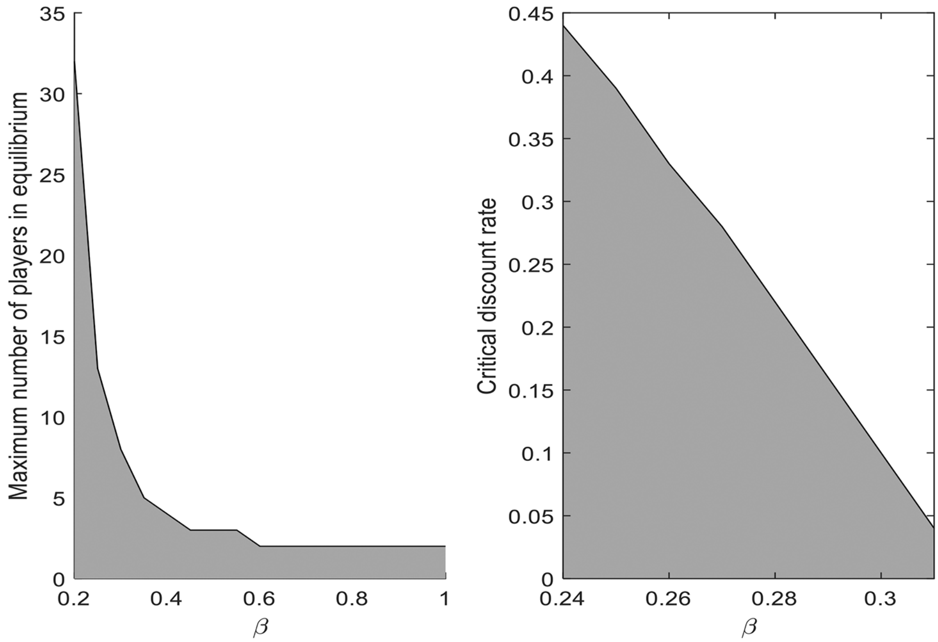

Figure 1. Maximum Number of Cooperative Players and Critical Discount Rates as a Function of the Scale Parameter, β. In the shaded gray areas, cooperation can be sustained. On the left-hand side, $\rho = 0.10$; on the right-hand side, $n = 8$.

of β, we have a corner solution, in which the free-rider effort goes to zero. Recall our earlier comment about a low value of β driving the detected deviator(s) out of the fishery.

The right-hand side of figure 1 illustrates the relationship between the scale parameter and the discount rate. As β gets lower, cooperation can be sustained with a higher discount rate, or to turn this around, with $n = 8$, stability cannot be maintained at high discount rates unless β is low.

In the example, with $n = 8$, stability cannot be maintained unless $\beta \leq 0.31$, even if $\rho = 0.00$, which seems anomalous, to say the least. This must be ascribed to the fact that, in the example, the time horizon is short, only 30 periods. If the time horizon did, for example, approach infinity, then stability would be assured, if $\rho = 0.00$, even if $\beta = 1$.

We conclude this example with a qualification. The example shows that the β is compatible with stability, given different numbers of players and different discount rates. We talked earlier about the introduction of the club good ensuring that punishing the deviator will not inflict equal punishment upon the non-deviators. The non-deviators, if rational, will want to try to ensure, as much as possible, that punishing the deviator rewards, rather than punishes, the virtuous. This could lead to β being set even lower than prescribed by the example.

CONCLUSIONS

The challenge of achieving stable cooperative fisheries management arrangements has become increasingly important. Many of the game theory analyses of such arrangements, with the most common being based upon repeated games with trigger strategies models, have produced pessimistic results. Unless the number of players is low, or unless the returns from cooperation are low, or unless the discount rate is very low, free riding will be an intractable problem, or so it appears. Yet the empirical evidence amassed by Nobel laureate Elinor Ostrom and her colleagues on the cooperative management of common-property resources, including fisheries, appears to refute the aforementioned pessimism.

What the evidence amassed by Ostrom and her colleagues points to is the existence of what might be termed "social capital" as a force for strengthening cooperation. The problem is how to incorporate effectively such social capital into game theoretic fishery models. This paper attempts to do just that, by first treating the social capital as a type of club good, where the club good will include all of the benefits arising from belonging to the club, such as sharing information and good social standing. Free riders detected are punished by losing some or all of the benefits of the club. The costs of club punishments can then be captured, this paper argues, by a simple scale parameter, affecting the penalty function. With the introduction of the scale parameter, the social capital, and the consequences arising therefrom, are effectively incorporated into the game theory model.

The paper commences with what it refers to as a standard baseline model, with symmetric players, playing a repeated partition function game, with trigger strategies. The model is then extended to include the club good through a scale parameter. The baseline model is symmetric throughout. In the extended model, the game is symmetric under full cooperation, full noncooperation, and if the deviator is undetected. If the deviator is detected, the game then becomes asymmetric, with the penalty of punishements imposed by the club, up to the point of outright banishment from the club, being seen as the equivalent of higher fishing effort costs. Asymmetry matters. In the baseline model, detection of the deviator results in a reversion to full noncooperation, leading to punishment of the deviator, but also of the punishers—the curse of symmetry. In the extended model, detection of the deviator leads to punishment of the deviator, but not of the virtuous, which continue to play a cooperative game.

It is then demonstrated that, given the club good, stability of the cooperative game solution can be achieved at discount rates and number of players far higher than those leading to stability in the standard baseline model. The scope for stability of the cooperative game solution is thus greatly expanded.[11]

Furthermore, and of utmost importance, in the baseline model all of the relevant parameters are exogenous to the model. In the extended model, there is a key parameter, the scale parameter, which is endogenous to the model. The members of the coalition are able to exert control over the design of the club good, and hence over the degree of punishment arising from banishment. In so doing, the members of the coalition can ensure that, far from being punished when punishing deviators, they will actually benefit.

Having said this, it is to be emphasized that in this model, no player in the grand coalition *in good standing* can be excluded, although a player in serious violation of the club rules obviously can be. Therefore, despite the fact that the coalition may be made better off by forcing a player to leave the coalition, excluding players in good standing from the coalition is not a legitimate strategy.

The authors are thus driven to the conclusion that the claim of Elinor Ostrom and her colleagues, to the effect that the predictions of what we term the standard game theory models are excessively pessimistic, is indeed vindicated.

11. Let it also be stressed that the penalties imposed upon the defectors are, using the Nordhaus (2015) definition, strictly internal in nature.

This paper has confined itself to the cooperative management of domestic, intra-EEZ, fisheries. What is the relevance of what we have termed the extended, club good, model to the cooperative management of international fisheries? Obtaining the answer to this important question is beyond the scope of this paper and will be the subject of future research. At this stage, it is the conjecture of the authors that what they have called the club good model is, in fact, highly relevant.

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