International Fisheries Agreements and Non-consumptive Values

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Abstract

The management of internationally shared fish stocks is a major economic, environmental and political issue. According to international law, these resources should be managed cooperatively under international fisheries agreements (IFAs). This paper studies the formation and stability of IFAs through a coalition game that accounts for both direct consumptive values (harvesting profits) and non-consumptive values of the fish stock per se. The results show that accounting for non-consumptive values helps conserve the fish stock in that equilibrium fishing efforts are smaller and fish stock larger than without non-consumptive values under all possible coalition scenarios (full, partial and no cooperation). However, considering non-consumptive values does not affect the outcome of the game in terms of the prospects for cooperation: even with substantial non-consumptive benefits, the outcome is full non-cooperation. Hence, the trap of non-cooperation in international fisheries management cannot be overcome simply by explicitly accounting for non-consumptive values within IFAs.

1. Introduction

The strategic interactions pertaining to the harvesting of shared fish stocks have been studied extensively applying game theoretic modeling tools, starting with the seminal paper by Munro (1979). For analyzing the formation of international fisheries agreements (IFAs), which involve several countries joining together to manage a fish stock, coalition formation games have become the standard tool since the introduction of the partition function game approach by Pintassilgo (2003). The coalition formation literature on IFAs has been steadily growing over recent years (Pintassilgo et al., 2015).

The game theoretic literature on shared fishery resources has largely focused on the payoff derived from harvesting fish. Yet a significant part of the total economic value of marine resource stocks may be attributable to benefits aside from direct consumption of products from the stock (e.g., Ferrara and Missios, 1998; Loomis and White, 1996; Mazzanti, 2001; Turner et al., 2003).[1] Non-consumptive value encompasses direct non-consumptive use value, such as watching fish, as well as non-use values ranging from existence values to option and bequest values (see e.g. Mazzanti, 2001).[2] If resource managers are assumed to be maximizing overall net benefits, non-consumptive values cannot be ignored in deriving an optimal outcome (see e.g. Ferrara and Missios, 1998; Alexander 2000; Yamazaki et al., 2010). However, despite the potentially significant role of non-consumptive values in determining optimal management strategies, the combination of game theory and non-consumptive values in the analysis of shared fishery resources is scarce – to our knowledge, only two previous papers, Missios and Plourde (1997) and Ferrara and Missios (1998), have addressed non-consumptive values and strategic considerations. These papers show in a two-country framework that non-consumptive values reduce the total harvest relative to the case of only consumptive values, and may have important implications for the strategic behavior of countries with an interest in the resource stock.

The contribution of the present paper is that it extends the analysis of coalition formation in fisheries management to the case where at least one country derives non-consumptive values from the resource stock. While many internationally shared fishery resources are harvested by several rather than by just two countries, the models developed in Ferrara and Missios (1998) and Missios and Plourde (1997) can only be applied to the case where a fish stock migrates across the boundaries between the waters of just two nations. Analyzing the potential for self-enforcing international agreements on fisheries management in this case calls for analyzing coalition formation rather than two-country bargaining solutions.

In our approach, as in Ferrara and Missios, players receive benefit from both harvest and the level of the fish stock. Similar approaches in a general resource extraction context include, among others, Conrad and Clark (1987), Alexander (2000), Harstad and Liski (2012) and Lasserre and Smulders (2013). Conrad and Clark (1987) is an early example of a social welfare function that attributes value to the stock itself, referred to as the preservation value of the stock by the authors. Alexander (2000) analyzed the implications of non-consumptive values for species' survival. He concluded that models and policies that fail to consider non-consumptive values are likely to result in inappropriately low optimal population levels. Harstad and Liski

[1] Measuring the non-consumptive values attributable to environmental resources has become an important research area within environmental economics (Smith, 2000). Such values cannot in general be measured based on market transactions. Non-market valuation methods have been developed to derive benefit estimates where market information is not available (see, e.g., Arrow et al., 1993). A common example of the application non-market valuation methods to fisheries includes the measurement of recreational values (e.g., Håkansson, 2008).

[2] Both direct and indirect non-consumptive values can be seen as part of ecosystem services, a concept popularized by the Millennium Ecosystem Assessment (2005).

(2012) compared extraction levels by several non-cooperating resource users to socially optimal extraction levels in a model where each user values the stock as well as extraction from the stock. Their focus was on inefficiencies arising from strategic behavior, whereas solutions for overcoming such inefficiencies were left as a topic for future research. Furthermore, their stylized model setup assumed that the stock size is exogenously given, so conservation aspects were not addressed. Lasserre and Smulders (2013) modeled the interactions between renewable and non-renewable natural resources, allowing for the possibility that society derives direct utility from resource stocks. While Lasserre and Smulders did not carry out a full analysis of non-consumptive values and resource extraction, they concluded, based on surveys, that this link is of importance.

In a fisheries context, Yamazaki et al. (2010) showed that accounting for non-consumptive values is an important issue for optimal marine reserve design and substantially decreases the frequency of rotating of non-fishing areas. Finally, while non-consumptive values and strategic behavior among resource users has received relatively short shrift, game theory was incorporated as a tool for estimating non-use values already in the 1970's when Randall et al. (1974) suggested using bidding games to reveal respondents willingness to pay for environmental improvements in contingent valuation surveys.

The paper is organized as follows: Section 2 develops a bio-economic model and a coalition formation model that incorporate both harvesting and non-consumptive values of the fishery. The coalition formation game is solved backwards. Section 3 describes countries' optimal effort strategies in the second stage of the game and discusses the implications of non-consumptive values for equilibrium harvest levels under different coalition structures. Section 4 analyzes the countries' membership decision in the first stage of the game and discusses the effect of non-consumptive values on the size of the coalition. Section 6 presents the main conclusions.

2. Bioeconomic model and coalition formation model with non-consumptive values

Modelling the formation of an international fisheries agreement requires two main components: a bioeconomic model describing stock dynamics, harvest functions, revenues, fishing costs, and possible non-consumptive benefits; and a coalition formation model, that is, a game showing the strategic interactions between the different players, here countries. We next outline the bioeconomic model and the coalition formation game in Sections 2.1 and 2.2.

We consider three countries exploiting a transboundary fish stock. Each country receives consumptive benefits from harvest as well as non-consumptive benefits from the fish stock per se. The non-consumptive values considered here may entail both non-use values (option value, existence value, or bequest value) and non-consumptive use values (such as fish watching as recreational activity, or ecological functions). Initially we assume that the three countries are symmetric with regard to prices, costs, and non-consumptive values. The three-country setting is a modelling choice due to complexity arising from introducing a non-linear non-consumptive value component; a three-player game is analytically tractable yet maintains all the main components of a coalition formation game.

2.1 The bioeconomic model

By assumption, the growth of the fish stock follows a logistic growth function (2). Let X denote the size of the fish stock, and H_i and E_i the harvest and fishing effort of an individual country *i*. The relation between the fish stock, the harvests, and the fishing efforts exerted by the three countries is given by the following three equations:

$$\frac{dX}{dt} = G(X) - \sum_{i=1}^{3} H_i \tag{1}$$

$$G(X) = rX\left(1 - \frac{X}{k}\right) \tag{2}$$

$$H_i = qE_iX \tag{3}$$

where r denotes the intrinsic growth rate of the fish stock, k the carrying capacity of the ecosystem (and thus the equilibrium level of X in the absence of harvesting), q the catchability coefficient, and t time.

The variation of the stock level in time is given by the difference between stock growth $G(X)$ and total harvest (1). The inverted U-shaped logistic growth function (2) implies that stock growth increases up to a maximum value, often referred to as the maximum sustainable yield, and decreases thereafter. The harvest function of each country (3) is assumed to increase linearly with the catchability coefficient, its own the fishing effort, and the stock level.

The steady state relation between the stock level and the total fishing effort can be obtained by substituting (2) and (3) into (1) and setting $dX / dt = 0$, which yields

$$X^* = \frac{k}{r}\left(r - q\sum_{i=1}^{3} E_i\right) . \tag{4}$$

As shown by equation (4), the equilibrium stock is decreasing in the total fishing effort of the three countries, $\sum_{i=1}^{3} E_i$.

We focus on the symmetric case where the countries face an identical price of fish and cost of fishing effort. The payoff of each country is given by the sum of the commercial profits from harvest (direct consumptive value) and non-consumptive value:

$$\Pi_i = pH_i - cE_i + v_i(X) \tag{5}$$

where p is the price of fish, c the cost per unit of effort, and $v_i(X)$ the non-consumptive value of the fish stock for country i .

Regarding the functional form specification for the non-consumptive value $v_i(X)$, we assume that the non-consumptive value is positive when the stock is positive and zero when the stock is extinct: $v_i(0) = 0$. Moreover, we assume that the non-consumptive value increases with the stock until the carrying capacity of the environment is reached and obtains its maximum at the carrying capacity *k*, which imply that

$v_i'(X) > 0$, $\forall 0 \le X < k$, and $v_i'(k) = 0$. Finally, we also assume that the non-consumptive value increases at a decreasing rate with the stock level: $v_i''(X) < 0$. We incorporate these properties by adopting the quadratic functional form specification:

$$v_i(X) = A_i X - B_i X^2 . \tag{6}$$

We initially assume that the non-consumptive values are symmetric: $A_i = A$, $B_i = B$ and $v_i(X) = v(X)$ for all i (we will relax this assumption in section 5). Imposing the first-order condition for a maximum at k, $v'(k) = 0$, yields the following parameter relation: $B = \frac{A}{2k}$. Thus, the symmetric non-consumptive value function can be rewritten as:

$$v(X) = AX\left(1 - \frac{X}{2k}\right). \tag{7}$$

The non-consumptive value function increases with the parameter A. Hence, this parameter can be interpreted as a direct measure of the magnitude of the non-consumptive benefits.

Inserting (3), (4) and (7) into (5), each country's payoff can be written as:

$$\Pi_i = pqE_i \frac{k}{r}\left(r - q\left(\sum_{\ell=1}^{3} E_\ell\right)\right) - cE_i + A\frac{k}{r}\left(r - q\left(\sum_{\ell=1}^{3} E_\ell\right)\right)\left(1 - \frac{1}{2r}\left(r - q\left(\sum_{\ell=1}^{3} E_\ell\right)\right)\right). \tag{8}$$

Equation (8) indicates that an increase in the fishing effort by one country creates a negative externality to the other countries, through a decrease in the equilibrium stock level that reduces the other countries' revenue and non-consumptive value.

2.2 Coalition formation model

We model the formation of an international fishery agreement as a two-stage partition function game with three symmetric players. This game, denoted as $\Gamma(N, \Pi)$, is fully defined by the set of countries, $N = \{1, 2, 3\}$, and the partition function, Π. The partition function Π assigns payoffs to each country under each possible coalition structure, that is, under each partition of the set of countries. As explained below, we assume that only one non-trivial coalition will form. Here, non-trivial refers to a coalition with more than one country. Thus, a coalition structure is represented by $C = \{S, 1_{(3-m)}\}$, where S represents the coalition composed of m members, $m \in \{1,2,3\}$, and $1_{(3-m)}$ the vector of $3-m$ non-signatory countries acting as singletons. In this context, the overall coalition structure is fully characterized by the coalition S.

In the first stage of the game, each country decides whether to join the IFA (coalition) or remain a non-member and act as a singleton. We assume a setting with a single coalition and open membership (d'Aspremont et al., 1983), that is, only one coalition forms and any country is allowed to join the coalition.

Our focus is on the number of countries that join the IFA. The usual approach to equilibrium coalition size is based on ideas developed for cartel stability (d'Aspremont et al. 1983, Barrett 1994) and requires what is called internal and external stability, which corresponds to a Nash equilibrium in membership strategies. Internal stability means that no signatory country has an incentive to leave the coalition S to become a non-signatory, and external stability means that no non-signatory country has an incentive to join coalition S. The stability conditions are expressed formally as follows:

Internal stability: $\Pi_i^*(S) \geq \Pi_i^*(S \setminus \{i\}),\ \forall i \in S$ (9)

External stability: $\Pi_j^*(S) > \Pi_j^*(S \cup \{j\}),\ \forall\ j \notin S.$ (10)

In order to avoid unclear cases, we assume a strict inequality in the external stability condition. Thus, if a country is indifferent between joining coalition S and remaining outside, it will join the agreement. Coalitions that are both internally and externally stable are called stable.

In the second stage, given that some coalition S has formed in the first stage, countries choose their fishing effort levels. The *m* signatories set their effort levels so as to maximize the aggregate payoff to their coalition:

$$\max_{E_S} \sum_{i \in S} \Pi_i(S) = \sum_{i \in S} pqE_i \frac{k}{r}\left(r - q\left(\sum_{\ell=1}^{3} E_\ell\right)\right) - c\sum_{i \in S} E_i + mA\frac{k}{r}\left(r - q\left(\sum_{\ell=1}^{3} E_\ell\right)\right)\left(1 - \frac{1}{2r}\left(r - q\left(\sum_{\ell=1}^{3} E_\ell\right)\right)\right) \quad (11)$$

where E_S stands for a m-size vector with the fishing efforts of coalition S.

Each singleton, j, chooses an effort level that maximizes its own payoff :

$$\max_{E_j} \Pi_j = pqE_j \frac{k}{r}\left(r - q\left(\sum_{\ell=1}^{3} E_\ell\right)\right) - cE_j + A\frac{k}{r}\left(r - q\left(\sum_{\ell=1}^{3} E_\ell\right)\right)\left(1 - \frac{1}{2r}\left(r - q\left(\sum_{\ell=1}^{3} E_\ell\right)\right)\right) \quad (12)$$

Solving problems (11) and (12) simultaneously yields the Nash equilibrium fishing efforts of the second stage. Inserting these equilibrium fishing efforts into the countries' payoffs (equation 8), for each coalition structure, yields the partition function. Since the countries are symmetric, we assume an equal sharing of the coalitional worth. Finally, applying the conditions for internal and external stability, from (9) and (10), yields the equilibrium coalition structure. Thus, the game is solved backward for the subgame-perfect equilibrium.

In the following sections, we solve the fishing game using the backward induction sequence described above. Section 3 presents the solution to the second stage of the game, assuming that a coalition has been formed. Section 4 describes the solution to the first stage membership game, which determines the size of the IFA that will form.

3. Results of the second stage: the fishing effort game

There are three possible coalition structures that may arise as a result of the first stage membership game: full cooperation, partial cooperation and no cooperation. We next present the equilibrium fishing effort strategies and payoffs under each possible coalition structure.

3.1 Full cooperation

In the case of full cooperation, all three countries join the IFA, forming the grand coalition $S=\{1,2,3\}$. This coalition maximizes its aggregate worth:

$$\underset{E_1,E_2,E_3}{Max}\sum_{i=1}^{3}\Pi_i$$
$$= pq\sum_{j=1}^{3}E_i\frac{k}{r}\left(r-q\left(\sum_{i=1}^{3}E_i\right)\right)-c\sum_{i=1}^{3}E_i+3A\frac{k}{r}\left(r-q\left(\sum_{i=1}^{3}E_i\right)\right)\left(1-\frac{1}{2r}\left(r-q\left(\sum_{i=1}^{3}E_i\right)\right)\right).$$

From the first order conditions of this problem, we obtain the fishing effort of the coalition:

$$E_S=\sum_{i=1}^{3}E_i=AE_{FC}=\frac{pr^2(1-b)}{q(2rp+3A)} \tag{13}$$

where AE_{FC} stands for aggregate effort under full cooperation and $b=\frac{c}{pqk}$.

Parameter $b=\frac{c}{pqk}$ is commonly termed the "inverse efficiency parameter" as it increases with the cost per unit of effort and decreases with price, catchability and carrying capacity of the ecosystem. In the absence of non-consumptive values, parameter b is equal to the ratio of the open access equilibrium stock and the carrying capacity of the ecosystem (Pintassilgo et al. 2010). Therefore, $b\in[0,1[$, assuming that harvest is strictly positive under open-access.

Equation (13) indicates that the grand coalition aggregate effort AE_{FC} decreases with A, which represents the magnitude of non-consumptive benefits. Moreover, $\lim_{A\to+\infty}AE_{FC}=0$. That is, if the non-consumptive benefits tend to infinity, then it is optimal not to harvest.

The equilibrium stock level is obtained by inserting the optimal fishing effort of the coalition in (13) into (4):

$$X=k\left(1-\frac{pr(1-b)}{(2rp+3A)}\right). \tag{14}$$

The equilibrium payoff of the grand coalition is obtained by inserting the optimal fishing effort in the coalitional payoff:

$$\Pi_S = \frac{p^2 r^2 k (1-b)^2}{2(2rp+3A)} + \frac{3Ak}{2}. \tag{15}$$

By differentiating expressions (14) and (15) with respect to parameter A we conclude that both the stock level and the aggregate payoff increase with the non-consumptive benefits. Hence, as expected, if countries account for non-consumptive benefits and form a fully cooperative IFA, they will adopt more conservative fishing strategies, leading to larger stock levels.

3.2 Partial cooperation

We next describe the equilibrium fishing effort strategies in the case of a two-country coalition. Without loss of generality, we assume that the coalition is formed by countries 1 and 2, so that $S = \{1, 2\}$.

The coalition again maximizes the joint payoff of its members:

$$\underset{E_1,E_2}{Max} \sum_{i=1}^{2} \Pi_i$$
$$= pq\sum_{i=1}^{2} E_i \frac{k}{r}\left(r - q\left(\sum_{\ell=1}^{3} E_\ell\right)\right) - c\sum_{i=1}^{2} E_i + 2A\frac{k}{r}\left(r - q\left(\sum_{\ell=1}^{3} E_\ell\right)\right)\left(1 - \frac{1}{2r}\left(r - q\left(\sum_{\ell=1}^{3} E_\ell\right)\right)\right).$$

The singleton, country 3, maximizes its own payoff:

$$\underset{E_3}{Max}\, \Pi_3 = pqE_3 \frac{k}{r}\left(r - q\left(\sum_{\ell=1}^{3} E_\ell\right)\right) - cE_3 + A\frac{k}{r}\left(r - q\left(\sum_{\ell=1}^{3} E_\ell\right)\right)\left(1 - \frac{1}{2r}\left(r - q\left(\sum_{\ell=1}^{3} E_\ell\right)\right)\right).$$

Solving the first-order conditions to the two maximization problems simultaneously, we obtain the equilibrium fishing efforts of the coalition $S = \{1, 2\}$ and the singleton country 3:

$$E_S = \frac{r(rp-A)(1-b)}{3q(rp+A)} \tag{16}$$

$$E_3 = \frac{r(1-b)}{3q} \tag{17}$$

Differentiating (16) with respect to parameter A shows that the fishing effort of the coalition decreases with A. Hence, the larger the non-consumptive benefits the lower is the equilibrium fishing effort of the coalition. However, the equilibrium effort of the singleton does not depend on the magnitude of the non-consumptive benefits. Here, two opposite effects cancel each other out. On the one hand, an increase in the non-consumptive benefits provides an incentive for the singleton to reduce its fishing effort. On the other hand, the accompanying reduction in the fishing effort of the coalition provides an incentive for the singleton to increase its fishing effort. In the equilibrium the singletons fishing effort remains unchanged.

The aggregate effort under partial cooperation is given by:

$$AE_{PC} = E_S + E_3 = \frac{2r^2 p(1-b)}{3q(rp+A)}. \tag{18}$$

Inserting (18) into (4) yields the equilibrium stock level:

$$X = k\left(1 - \frac{2rp(1-b)}{3(rp+A)}\right). \tag{19}$$

As in the case of full cooperation, the larger are the non-consumptive benefits from the stock, the lower is the aggregate fishing effort and consequently the higher is the equilibrium stock level.

Inserting the effort levels from (16) and (17) into the payoff expressions yields the equilibrium payoffs of the 2-country coalition and the singleton:

$$\Pi_S = \frac{9kA^2 + 3pkrA\left(2-b^2+2b\right) + r^2 p^2 k\left(1-b\right)^2}{9\left(rp+A\right)} \tag{20}$$

$$\Pi_3 = \frac{9kA^3 + 6rpk\left(4-2b+b^2\right)A^2 + r^2 p^2 k\left(13-8b+4b^2\right)A + 2r^3 p^3 k\left(1-b\right)^2}{18\left(rp+A\right)^2}. \tag{21}$$

Both equilibrium payoffs increase with the magnitude of the non-consumptive benefits captured by parameter A, as can be confirmed by computing the respective derivatives. Under partial cooperation, larger non-consumptive benefits induce the countries forming the IFA to reduce their fishing effort. In contrast, the non-member chooses not to adjust its fishing effort, and instead free-rides on the conservation efforts of the IFA members. Overall, the aggregate fishing effort decreases, which results a larger equilibrium stock level.

3.3 No Cooperation

We now consider the case in which all the three countries behave as singletons. Each singleton $i \in \{1,2,3\}$ maximizes its own payoff:

$$\underset{E_i}{Max}\,\Pi_i = pqE_i \frac{k}{r}\left(r - q\left(\sum_{\ell=1}^{3} E_\ell\right)\right) - cE_i + A\frac{k}{r}\left(r - q\left(\sum_{\ell=1}^{3} E_\ell\right)\right)\left(1 - \frac{1}{2r}\left(r - q\left(\sum_{\ell=1}^{3} E_\ell\right)\right)\right).$$

Solving the first-order conditions to the three countries' maximization problems simultaneously yields the equilibrium fishing effort of each country:

$$E_i = \frac{pr^2\left(1-b\right)}{q\left(4rp+3A\right)}. \tag{22}$$

Hence, the aggregate fishing effort under no cooperation is:

$$AE_{NC} = \sum_{i=1}^{3} E_i = \frac{3pr^2\left(1-b\right)}{q\left(4rp+3A\right)}. \tag{23}$$

Under no cooperation, individual fishing efforts, and hence the aggregate effort, decrease with the magnitude of the non-consumptive benefits from the stock, denoted by *A*.

The stock level is obtained by inserting (23) into (4):

$$X^{*}=k\left(1-\frac{3pr\left(1-b\right)}{\left(4rp+3A\right)}\right). \tag{24}$$

The equilibrium payoff of each country is computed by inserting (22) and (23) into the payoff expression:

$$\Pi_i=\frac{9kA^3+24pkrA^2+r^2p^2k\left(13+6b-3b^2\right)A+2r^3p^3k\left(1-b\right)^2}{2\left(4rp+3A\right)^2}. \tag{25}$$

Differentiating Π_i with respect to the non-consumptive value parameter *A* shows that each country's equilibrium payoff increases with the magnitude of non-consumptive benefits. As in the cases of full and partial cooperation, the higher are the non-consumptive benefits, the lower is the aggregate fishing effort and consequently the larger the stock level.

3.4 Properties of the coalition formation game with non-consumptive values

Based on the payoffs obtained for the three different coalition structures, we can now establish three important properties related to the second stage that will be helpful for the subsequent analysis.

Proposition 1. Properties of the Coalition Game.

Let S and $S'=S\cup\{j\}$ be two coalitions formed in the first stage of the game, where S' is obtained from the merger of coalition S and country j.

(i) Positive Externalities: The payoff of country ℓ, who is neither a member of coalition S nor of S', is strictly higher under S' than under S: $\Pi_{\ell\notin S'}(S')>\Pi_{\ell\notin S}(S)$;

(ii) Superadditivity: if $\#S=2$ (that is, the size of the coalition is two countries), then the sum of the payoffs of coalition S and singleton j is strictly lower than the payoff of $S'=S\cup\{j\}$: $\sum_{i\in S}\Pi_i(S)+\Pi_{j\notin S}(S)<\sum_{i\in S'}\Pi_i(S')$, that is supperaditivity holds. If $\#S=1$, then superadditivity does not hold: $\Pi_{i\in S}(S)+\Pi_{j\notin S}(S)>\sum_{i\in S'}\Pi_i(S')$.

(ii) Global Efficiency from Cooperation: The aggregate payoff is strictly higher under S' than S: $\sum_{i\in S'}\Pi_i(S')+\sum_{\ell\notin S'}\Pi_\ell(S')>\sum_{i\in S}\Pi_i(S)+\sum_{\ell\notin S}\Pi_\ell(S)$.

Proof:

(i) In our game, the analysis of positive externalities is confined to the change from no cooperation to partial cooperation, as it is required that one country remain outside both the initial and the final coalition. Let S be a 1-country coalition, S' a 2-country coalition, and country ℓ neither a member of coalition S nor of S'. Then, using the payoffs in (25) and (21), we obtain:

$$\Pi_{\ell\in S'}(S')-\Pi_{\ell\in S}(S)=\frac{r(-pqk+c)^2(A+2rp)(6A+7rp)(3A+rp)^2}{18pq^2k(rp+A)^2(4rp+3A)^2}. \quad (26)$$

This expression is always positive, which proves that the game exhibits positive externalities.

(ii) Consider $\#S=2$. Then using (15), (20) and (21) we obtain:

$$\sum_{i\in S'}\Pi_i(S')-\left(\sum_{i\in S}\Pi_i(S)+\Pi_{j\notin S}(S)\right)=\frac{r^2(-pqk+c)^2(3A+rp)^2}{18k(2rp+3A)q^2(rp+A)^2}. \quad (27)$$

This expression is always positive and hence superadditivity holds for $\#S=2$.

Consider now $\#S=1$. Then using (20) and (25) we obtain:

$$\sum_{i\in S'}\Pi_i(S')-\left(\sum_{i\in S}\Pi_i(S)+\Pi_{j\notin S}(S)\right)=-\frac{r(-pqk+c)^2(3A+2rp)(3A+rp)^2}{9pq^2k(4rp+3A)^2(rp+A)} \quad (28)$$

This expression is always negative and hence superadditivity does not hold for $\#S=1$.

(iii) In order to prove this property it is sufficient to analyse the cases of $\#S=1$ and $\#S=2$. For $\#S=2$, the proof of global efficiency is identical to the proof of superadditivity in (ii).

If $\#S=1$, then, using (20), (21) and (25), we obtain:

$$\sum_{i\in S'}\Pi_i(S')+\sum_{\ell\notin S'}\Pi_\ell(S')-\left(\sum_{i\in S}\Pi_i(S)+\sum_{\ell\notin S}\Pi_\ell(S)\right) =\frac{r^2(-pqk+c)^2(9A+10rp)(3A+rp)^2}{18q^2k(rp+A)^2(4rp+3A)^2}. \quad (29)$$

This expression is always positive and therefore global efficiency always hold for $\#S=1$. ■

Proposition 1 establishes that the game presents positive externalities, as the payoff of a singleton increases when the other two countries form a coalition. Further, superadditivity does not hold under all coalition structures. Superadditivity fails to hold when singletons merge to form a 2-country coalition, which intensifies the free-rider problem emerging from the positive externality property. Superadditivity instead does hold when a singleton joins a 2-country coalition to form the grand coalition, which provides a force towards cooperation. However, in this case the positive externality effect is stronger, so that free-riding remains attractive. Finally, global efficiency from cooperation implies that the aggregate payoff increases along with the number of countries joining the coalition. Thus, more extensive cooperation produces larger aggregate payoffs, and the maximum aggregate payoff is obtained under the grand coalition.

Proposition 2. The aggregate effort level decreases with coalition size and with the magnitude of non-consumptive benefits under all coalition structures.

Proof.

From (13), (18) and (23), the aggregate efforts under full cooperation, partial cooperation and no cooperation are given by:

$$AE_{FC} = \frac{pr^2(1-b)}{q(2rp+3A)}; \quad AE_{PC} = \frac{2pr^2(1-b)}{3q(rp+A)}; \quad AE_{NC} = \frac{3pr^2(1-b)}{q(4rp+3A)}. \tag{30}$$

Applying some algebraic manipulations to the aggregate effort expressions yields the following comparisons:

$$AE_{FC} - AE_{PC} = -\frac{r^2(1-b)(rp+3A)}{3p(2rp+3A)q(rp+A)} \tag{31}$$

$$AE_{PC} - AE_{NC} = -\frac{r^2(1-b)(rp+3A)}{p(4rp+3A)q(rp+A)}. \tag{32}$$

As $0 \le b < 1$, both expressions are negative.

It follows directly from the expressions of the three aggregate efforts levels that they decrease with parameter *A*. ■

Proposition 2 establishes that the more countries join an IFA, the lower the aggregate fishing effort and, consequently, the larger the stock size. Furthermore, large non-consumptive benefits, as measured by parameter *A*, reduce aggregate fishing effort and increase stock size. Hence, both cooperation and non-consumptive values result in the conservation of the shared fish resource.

4. Results of the first stage: the membership game

Given the equilibrium fishing effort strategies for each possible coalition structure, derived in Section 3, we can now solve the membership game that takes place in the first stage.

Proposition 3. The equilibrium coalition structure is no cooperation irrespective of the magnitude of the non-consumptive values.

Proof.

The grand coalition $\{1,2,3\}$ is not a stable coalition structure, as the internal stability condition (9) does not hold. Applying the equal sharing rule to the payoff (15) and using (21), we obtain

$$\begin{aligned}\Pi_i^*(\{1,2,3\}) - \Pi_i^*(\{1,2,3\}\setminus\{i\}) &= -\frac{r(-pqk+c)^2(2A+rp)(3A+rp)^2}{18k(2rp+3A)q^2p(rp+A)^2} \\ &< 0, \qquad \forall\, i \in \{1,2,3\}.\end{aligned} \tag{33}$$

The expression on the right hand side is always negative and hence condition (9) does not hold.

The 2-country coalitions are also not internally stable. Applying the equal sharing rule to the payoff in (20) and using (25) yields

$$\Pi_i^*\left(\{1,2\}\right)-\Pi_i^*\left(\{1,2\}\setminus\{i\}\right)$$
$$=-\frac{r\left(-pqk+c\right)^2\left(2rp+3A\right)\left(3A+rp\right)^2}{pq^2k\left(rp+A\right)\left(4rp+3A\right)^2}<0,\ \forall\ i\in\{1,2\}. \quad (34)$$

According to (34) the difference between the payoff of any country in a 2-country coalition $\{1,2\}$ and the payoff to the country after leaving that coalition is negative. Therefore, 2-country coalitions are also not internally stable.

The coalition structure formed only by singletons is internally stable by definition. Since the countries are symmetric by assumption, this coalition structure is also externally stable as the 2-country coalitions are not internally stable. The coalition structure formed by singletons is therefore stable and the unique equilibrium coalition structure. ■

Proposition 3 shows that accounting for non-consumptive values does not change the outcome found by Pintassilgo and Lindroos (2008) for shared fisheries with only commercial profits (use values from harvest). That is, the equilibrium coalition structure is always full non-cooperation. The trap of non-cooperation persists despite countries attributing non-consumptive values to the stock and regardless of the magnitude of non-consumptive values.

5. Conclusion

This paper presents a model of coalition formation in transboundary fisheries management in the case where countries take into account both profits from harvesting and non-consumptive values from the fish stock per se. While the three-country model presented is relatively simple, it suffices to highlight the strategic interactions in play when a fish stock migrates across the boundaries between the waters of several countries, or resides in the high seas.

In contrast to previous papers on transboundary fisheries management with non-consumptive values, where analysis was limited to a two-country framework, the present paper analyses coalition formation and shows that accounting for non-consumptive values does not affect the outcome in terms of the prospects for cooperation. Although accounting for non-consumptive values decreased the aggregate fishing effort under all possible coalition scenarios (full, partial and no cooperation), the outcome of the game was full non-cooperation. This result holds regardless of the magnitude of the non-consumptive values. That is, including non-consumptive values does not suffice to overcome the trap of non-cooperation in transboundary fisheries management.

A key message that emerges from our analysis is that cooperation in the management of internationally shared fish stocks cannot be fostered by accounting for non-consumptive values. Hence, other measures are required to stabilize IFAs. These measures should strengthen the role of IFAs in the management of the resources and limit the ability of non-member countries to free-ride. For instance, Kwon (2006) and Long and Flaaten (2011) show that the prospects of cooperation are much higher if the coalition takes the role of a Stackelberg leader in fishing effort decisions. Munro (2007) stresses the need to address the so called "unregulated fishing", that is, fishing activities undertaken in the high seas in contravention of the management regime set by the IFA, by countries that did not join the agreement.

Our analysis did not include non-commercial use values from recreational harvest. In essence, benefits from recreational harvest could be modelled similarly to those from commercial harvest, as a function of recreational fishing effort (see, e.g., Kulmala et al., 2008). A potential topic for future research would be to examine whether asymmetries in use values attributable to recreational harvest could help sustain cooperation as the outcome of the game. Another potential topic for future research would be to examine how the order in which countries harvest the stock affects the prospects for cooperation. Here, we proceeded from the assumption that countries move simultaneously. As indicated in Kwon (2006) and Long and Flaaten (2011), a game structure where countries move sequentially, with one country acting as a leader for instance because of geographic proximity to the fish stock, could yield different conclusions regarding the potential for cooperation.

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