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INTERNATIONAL FISHERIES AGREEMENTS: THE FEASIBILITY AND IMPACTS OF PARTIAL COOPERATION

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International Fisheries Agreements: The feasibility and impacts of partial cooperation[1]

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Abstract: *This paper deals with partial cooperation among countries involved in the exploitation of straddling and highly migratory fish stocks. We analyse the feasibility of coalition structures and their impacts on fishing efforts by means of games in partition function form. Furthermore, we demonstrate that the modified Shapley value is an appropriate device for the division of the gains from cooperation.*

Keywords: *international fisheries, overexploitation, partial cooperation, games in partition function form, competitive equilibrium, modified Shapley value.*

1 Introduction

The oceans' fish stocks have been exploited as never before. Most of the world's marine fishing areas have already reached their maximum potential for fish captures (UN, 2002). FAO (2000) shows that about 47 to 50 percent of marine fish stocks are fully exploited and are, therefore, producing catches that have either reached or are very close to their maximum limits, with no room for further expansion. Another 15 to 18 percent are overexploited and there is an increasing likelihood that catches from these stocks will decrease, if remedial action is not taken to reduce or revert overfishing conditions.

The world catch of marine fish has continued to rise in spite of extensions of fisheries jurisdictions (Exclusive Economic Zone or EEZ) in the mid-1970s to 200 miles, though at a slower rate. To regulate the exploitation of the ocean's fish stocks further, several international agreements have been concluded. The relevant international law was codified, developed and enhanced through, inter-alia, the entry into force of the UN Convention on the Law of the Sea in 1994, the adoption of the Convention on Straddling Fish Stocks and Highly Migratory Fish Stocks in 1995 (abbreviated as 1995

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UN Fish Stocks Agreement), and the adoption of the FAO Code of Conduct for Responsible Fisheries in the same year. Moreover, an international jurisprudence on fisheries related issues is slowly emerging through the work of the International Tribunal on the Law of the Sea (for details see Green Paper, 2001).

The 1995 UN Fish Stocks Agreement calls for those nations who wish to participate in the harvesting of the fish resources in the high seas, but are not currently members of the relevant Regional Fisheries Management Organization (RFMO), to declare a willingness to join and to enter into negotiations over mutually acceptable terms of entry. Under the terms of the UN Convention on the Law of the Sea, which is of direct relevance to the 1995 UN Fish Stocks Agreement, coastal states (CSs) and distant water fishing nations (DWFNs) shall apply the precautionary approach to conservation, management and exploitation of straddling and highly migratory fish stocks in order to protect the living resources and preserve the marine environment. In addition, all states are obliged to take conservation and management measures necessary for the conservation of the living resources of the high seas (Article 117). Moreover, international cooperation and negotiations are required for all states involved in the exploitation of such resources (Article 118).

Although the 1995 UN Fish Stocks Agreement entered into force on 11 December 2001 (UN, 2002), the precise meaning of the provisions describing these obligations is not clear nor the manner in which they will be applied. For example, Article 63 expresses that the states concerned should seek to agree on conservation measures applicable beyond the EEZs, either directly or through appropriate RFMOs. Article 64 requires that coastal and other states whose nationals fish in the region "*shall cooperate*" directly or through appropriate international organizations with a view to ensuring conservation and optimum utilization. Furthermore, Article 118 on high seas stocks, referring to the need to establish RFMOs, provides that states exploiting such stocks or different ones in the same area "*shall enter into negotiations*" with a view to taking the measures necessary for the conservation of the living resources concerned.

Due to inter alia its ambiguities, the 1995 UN Fish Stocks Agreement provides little or no guidance as to how cooperation, through a RFMO, is to be effected (Munro, 2000). The lack of cooperation has resulted in conflicts between coastal states and distant water fishing states (Bjϕrndal and Munro, 2003)[2]. Moreover, overexploitation has continued and the need

[2]According to these authors, the inadequacies of Part VII, section 2 (Articles 116-120),

for a cooperative management regime is evident.[3]

The literature on the economic analysis of the 1995 UN Fish Stocks Agreement notes that the new member or participant problem is one of the most important problems in the high seas fishery management (Kaitala and Munro, 1993 and 1995; Bjϕrndal and Munro, 2003), since the interests of current members of the RFMO and of the applicants are often strongly opposed: the current members face the likelihood of having to give up a portion of their present quotas to the newcomer, and the applicant believes that it may be better off by staying outside of the coalition and continuing harvesting while facing fewer constraints. According to Kaitala and Munro (1997), the likelihood of achieving stable cooperation will be very low if the new member problem is mishandled. In addition, Datta and Miraman (1999) show that with an increasing number of countries, the inefficiency of the noncooperative equilibrium generated by the common access feature of high seas dominates and overharvesting increases. Although the nations involved in a regional fishery resource often recognize an advantage in cooperative management of the resource, on-going negotiations over harvest allotments often have proven to be arduous and frustrating, and interrupted by brief but astonishingly violent 'fish wars'.

This paper examines how a RFMO might successfully achieve effective control of a high seas fishery in the context of partial cooperation. We consider the high seas fishery stock as common property and assume that all nations are allowed to exploit it. We view concluding a Regional Fishery Agreement (RFA) as a game, where countries freely decide whether or not to join a coalition (i.e. a RFMO)[4]. That is, we consider a management situation where a coalition of countries, say S, cooperate and where one or several groups of countries stay outside S. The coalition member of S will coordinate their inputs so as to maximize their incomes. However, coalition S's income will be affected by a negative externality due to the input of those who do not belong to S.

The question that we deal with in this paper is the feasibility of partial cooperation and its impacts on fishing efforts. Moreover, we analyze how to allocate property rights among fishing nations that have expressed an

of the UN Convention pertaining to the management of high seas fisheries are the source of the lack of cooperation and conflicts.

[3]For a review of the history of the 1995 UN Fish Stocks Agreement as well as its implementation, see Bjϕrndal and Munro (2003).

[4]For related applications of cooperative game theoretic approaches to high seas fishery management, see, for example, Li (1998), Lindroos (2000), Bjϕrndal et al. (2000) and Pintassilgo (2002).

interest in sustainable exploitation of a fish stock in a partial cooperative setting. Particulary, we examine the feasible allocations of property rights among members of a given RFMO and coalitions of potential entrants.

In this paper, the feasibility and impacts of partial cooperation are analyzed by means of games in partition function form. This class of games was introduced in Thral and Lucas (1963) and is a generalization of characteristic function form games. The partition function form game allows the complements to split into coalitions in an arbitrary manner, while the classical characteristic function form game is defined in terms of coalitions and their complements only. We apply the modified Shapley value as a device for the division of the gains from partial cooperation. We observe that the emphasis in this paper is on the cost function rather than on the production function.

The paper is organized as follows. The next section presents the basic model and introduces notations and definitions. Section 3 analyses the effects of partial cooperation in terms of fishing efforts. Section 4 demonstrates that the modified Shapley value is a feasible solution concept for RFMOs. Concluding remarks follow in the last section.

2 The model and definitions

We begin by specifying a static model[5] of a common fishery resource as a n-person game (c.f. Funaki and Yamato, 1999; and Cornes and Hartley, 2000). Let $N = \{1, 2, ..., n\}$ be the set of n fishing nations, with generic element $j \in N$. Let $e = (e_1, e_2, ..., e_n)$ be a vector of fishing efforts, where $e_j \geq 0$ is country j's fishing effort, and let $e_N = \sum_{j=1}^{n} e_j$ be the aggregate fishing effort of all countries.

We introduce the production function $f(e_N)$ that specifies the amount of fish caught for each value of the total effort e_N. We assume that effort as input is homogenous and that all countries are equally likely to catch a fish per unit of effort. This implies that the share of the total harvest obtained by country j is directly proportional to the share of country j's effort in total effort e_N. In other words, the harvest of country j is given by $\frac{e_j}{e_N} f(e_N)$ for a given fish stock[6].

Different levels of technology efficiency among countries are represented

[5] That is, we assume a situation where the fishing nations choose across different possible steady states, ignoring the transitional dynamics.

[6] Note that the distribution of fish is not a result of negotiations among fishing countries; it is simply a reflection of the dependence of harvesting on its effort level e_j and e_N.

by the cost functions $c_j(e_j)$. Normalizing the price of the resource to unity, the net rent or benefit of country j is given by

$$\pi_j(e_1, e_2, ..., e_n) = \frac{e_j}{e_N} f(e_N) - c_j(e_j), \tag{1}$$

where $\pi_j(0, 0, ..., 0) = 0$.

We make the following assumptions:

Assumption **A1**: $f(.)$ is twice continuously differentiable, $f''(.) < 0$ (i.e. strictly concave for $e_N > 0$)[7], and $f(0) = 0$.

Assumption **A2**: $c_j(.)$ is continuously differentiable, increasing and convex for every j.

To simplify the analysis, we assume that $c_j(e_j) = c_j e_j$, where $c_j > 0$ for every $j \in N$.

Assumption **A3**: $0 < c_j < f'(0)$, for every $j \in N$

This assumption guarantees the existence of an interior solution.

For every $e = (e_1, e_2, ..., e_n)$, and $i \in N$ we define $e_{-i} = (e_1, ..., e_{i-1}, e_{i+1}, ..., e_n)$. In a similar vein, a vector $e = (e_1, e_2, ..., e_n)$ is written as $e = (e_i, e_{-i})$.

The above assumptions imply that the benefit function (1) is continuously differentiable and strictly concave on e_j. Particularly, the biological constraints that the benefit function is decreasing for e_N large enough is met

- A vector of effort $e^* = (e_1^*, e_2^*, ..., e_n^*)$ is said to be a *competitive equilibrium* or Nash equilibrium (NE) if $\forall i \in N$, and $\forall\ e_i \geq 0$

$$\pi_i(e_i^*, e_{-i}^*) \geq \pi_i(e_i, e_{-i}^*), \tag{2}$$

where $e_i^* \geq 0$, $\forall i \in N$.

The assumptions A1-A3 guarantee the existence of a competitive equilibrium. Moreover, this equilibrium is unique (Theorem 1 and Corollary 1 in Watt, 1996).

[7]This assumption implies that the additional catch from an extra unit of effort will clearly decrease as the total effort expended increseases, i.e. there are decreasing returns to fishing effort.

In addition to the above mathematical assumptions (A1-A3), we make the following behavioural assumptions A4-A5.

Assumption **A4**: a country is free to enter or leave a coalition. When a country defects from a coalition defectors either play as singletons or form a new coalition.

Assumption **A5**: when countries coordinate to form a coalition, their objective is to maximize the aggregate benefit, given the strategies of the others.

We introduce the following notions and definitions that will be used to analyze partial cooperation.

- A *coalition structure,* κ, is a partition of the set N of countries. Let $\mathbb{P}(N)$ be the set of all partitions of N. So, a coalition structure $\kappa \in \mathbb{P}(N)$ means that $\kappa = \{S_1, ..., S_m\}$, $N \supseteq S_j \neq \emptyset$, $S_j \cap S_k = \emptyset$, for all $j, k = 1, ..., m$, $j \neq k$ and $\cup_{j=1}^{m} S_j = N$.

For a given $\kappa \in \mathbb{P}(N)$, let $|\kappa|$ denote the cardinality of κ (i.e. if $\kappa = \{S_1, ..., S_m\}$ then $|\kappa| = m$). The partition which consists of singleton coalitions only, $\kappa = \{\{1\}, \{2\}, ..., \{n\}\}$, is denoted by $[N]$ whereas the partition which consists of the grand coalition only is denoted by $\{N\}$.

- A pair (S, κ) which consists of a coalition S and a partition κ of N to which S belongs is called an *embedded coalition.*

Let $\mathbb{E}(N)$ denote the set of embedded coalitions, i.e.

$$\mathbb{E}(N) = \{(S, \kappa) \in 2^N \times \mathbb{P}(N) |\ S \in \kappa\}.$$

Definition 2.1 A mapping

$$w : \mathbb{E}(N) \longrightarrow R$$

that assigns a real value, $w(S, \kappa)$, to each embedded coalition (S, κ) is called a *partition function*. The ordered pair (N, w) is called a *partition function form game.*

The value $w(S, \kappa)$ represents the payoff of coalition S, given that coalition structure κ forms. For a given partition $\kappa = \{S_1, S_2, ..., S_m\}$ and a partition function w, let $\overline{w}(S_1, S_2, ..., S_m)$ denote the m-vector $(w(S_i, \kappa))_{i=1}^{m}$.

It will be convenient to economize on brackets and suppress the commas between elements of the same coalition. Thus, we will write, for example, $w(\{i,j,k\}, \{\{i,j,k\},\{l,h\}\})$ as $w(ijk, \{ijk, lh\})$, and $\overline{w}(\{ikj\},\{lh\})$ as $\overline{w}(ijk, lh)$. The set of partition function form games with player set N is denoted by $PFFG^N$.

Definition 2.2 Let (N, w) be a partition function form game and $\kappa \in \mathbb{P}(N)$.

(i) coalition $S \in \kappa$ is *feasible under coalition structure* κ if

$$w(S, \kappa) \geq \sum_{i \in S} w(i, [N])$$

(ii) a coalition structure $\kappa \in \mathbb{P}(N)$ is *a feasible structure* if all coalitions are feasible under coalition structure κ, i.e.

$$w(S, \kappa) \geq \sum_{i \in S} w(i, [N]), \text{ for all } S \in \kappa$$

A feasible coalition implies that the worth of its members is at least as much as their worth under the stand-alone structure. In a similar vein, a coalition structure is feasible if the worth of each coalition in the coalition structure is at least as much as its stand-alone worth. A feasible coalition structure for a given game (N, w) is called a *partial cooperation.*

Example 2.1 Consider the game (N, w), where $N = \{1, 2, 3, 4\}$, the players are identical and w is given as follows.
$w(i, [N]) = 3$, $w(i, \{i, j, N \backslash \{ij\}\} = 2$, $w(i, \{i, jkl\}) = 3$,
$w(ij, \{ij, k, l\}) = 4$, $w(ij, \{ij, kl\}) = 5$, $w(ijk, \{ijk, l\}) = 10$,
$w(\{N\}) = 11$.
In this example, every coalition formed by 3 players such as $\{i, j, k\}$, has $w(ijk, \{ijk, l\}) \geq w(i, [N]) + w(j, [N]) + w(k, [N])$, while the value for a singleton in this coalition structure is
$w(l, \{ijk, l\}) = 3 = w(l, [N])$.
For every coalition consisting of 2 players, we have two cases:
(i) if $\kappa = \{ij, kl\}$ then $w(\{ij\}, \kappa) < w(\{i\}, [N]) + w(\{j\}, [N])$,
(ii) if $\kappa = \{ij, k, l\}\}$ then $w(\{ij\}, \kappa) < w(\{i\}, [N]) + w(\{j\}, [N])$ and
$w(i, \{i, j, N \backslash \{ij\}\} = 2 < w(i, [N])$.
In addition, $w(\{N\}) < \sum_{i=1}^{4} w(i, [N])$.
Hence, feasible coalition structures are: $\{i, jkl\}$.

Definition 2.3 A *solution* of $PFFG^N$ is a function Ψ which associates with each game (N, w) in $PFFG^N$ a vector $\Psi(N, w)$ of individual payoffs in $\mathbb{R}^N$, *i.e.* $\Psi(N, w) = (\Psi_i(N, w))_{i \in N} \in \mathbb{R}^N$.

We now turn to the case that some countries agree to form a coalition S, $S \subseteq N$. Since countries have different technologies, and each country is free to enter or leave a coalition, we consider the case in which cooperation among countries is possible in term of *transferable technologies*[8] (c.f. Norde *et al.* 2002). This implies that the cost function of coalition S, $c_S(.)$, is the cheapest cost function which is available among members in their coalition, i.e.

$$c_S(e_S) = \min_{j \in S}\{c_j(e_S)\}, \tag{3}$$

where $e_S = \sum_{j \in S} e_j$ is the total effort of S.

Suppose that a coalition structure $\kappa = \{S_1, S_2, ..., S_m\}$ is formed ($m \leq n$). Total effort for an admissible coalition structure S_i in κ is denoted by e_{S_i}. The benefit function of coalition S_i is defined by

$$\pi_{S_i}(e_{S_i}, e_{-S_i}) = \frac{e_{S_i}}{e_N} f(e_N) - c_{S_i}(e_{S_i}), \tag{4}$$

where $e_{-S_i} = (e_{S_1}, ..., e_{S_{i-1}}, e_{S_{i+1}}, ..., e_{S_m})$

- A non-negative vector $e^* = (e^*_{S_1}, e^*_{S_2}, ..., e^*_{S_m})$ associated with coalition structure $\kappa = \{S_1, S_2, ..., S_m\}$, is called a *competitive equilibrium* under coalition structure κ (or *equilibrium under* κ) if for all $i \in \{1, 2, ..., m\}$, and $e_{S_i} \geq 0$

$$\pi_{S_i}(e^*_{S_i}, e^*_{-S_i}) \geq \pi_{S_i}(e_{S_i}, e^*_{-S_i}). \tag{5}$$

Note that if $m = n$, then (5) is the definition of Nash equilibrium, and if $m = 1$ then it presents Pareto efficiency.

The existence of a unique competitive equilibrium under a given coalition structure is obvious since the strategy sets are 1-dimensional and the $m-$person game with payoff functions (4) is obtained[9] from the $n-$person game with payoff functions (1).

We are now in a position to define the fishery game in partition function form.

[8] For example, cooperation may lead to an exchange of vessels or labor among coalition partners.

[9] The assumptions A1-A3 still hold for this game.

Definition 2.4 A *fishery game in partition function form (FGPFF)* is an ordered pair (N, π), where N is the set of players and π is the partition (benefit) function derived from competitive equilibrium e^* under κ such that

$$\pi(S_i, \kappa) = \pi_{S_i}(e^*_{S_i}, e^*_{-S_i}) \text{ for all } (S, \kappa) \in \mathbb{E}(N), \tag{6}$$

with $\pi_{S_i}(e)$ defined by (4).

The set of fishery games in partition function form with player set N is denoted by $FGPFF^N$.

Let $\kappa(S_i)$ denote a coalition structure κ, where S_i belongs to. Note that $\pi(S_i, \kappa)$ may differ from $\pi(S_i, \kappa')$ since there exist many coalition structures which a coalition S_i may belong to, while the equilibria under coalition structures κ and κ' are different (c.f. there is a presence of externalities).

In the remainder of this paper, we use the notations $\pi(i, [N])$ and $\pi(S_i, \kappa)$ to denote the payoff of a single coalition $\{i\}$ in the Nash equilibrium and the payoff of a coalition S_i under coalition structure κ, respectively.

3 Implications of partial cooperation

In this section we analyze various impacts of coalitions and coalition structures. For each coalition structure $\kappa = \{S_1, S_2, ..., S_k\}$, let $e^*(\kappa)$ be total effort associated with κ, i.e. $e^*(\kappa) = \sum_{j=1}^{k} e^*_{S_j}$, where $\{e^*_{S_1}, e^*_{S_2}, ..., e^*_{S_k}\}$ is the unique competitive equilibrium under κ. Let $\pi(e^*(\kappa)) = \sum_{j=1}^{k} \pi(S_j, \kappa)$ be total net rents or benefits associated with κ at equilibrium $e^*(\kappa)$, where $\pi(S_j, \kappa)$, defined by (6), is the net rent of coalition S_j under κ.
Without loss of generality, we assume that $c_1 \leq c_2 \leq ... \leq c_n$. Thus, condition A.2 implies: $0 \leq c_n < f'(0)$.

For each coalition structure κ, a straightforward result is that in the competitive equilibrium a coalition with lower c_{S_i} has a higher fishing effort level e_{S_i}.

Proposition 3.1 *For every coalition structure κ, the lower the marginal cost c_{S_i}, the higher the effort level in the coalition structure equilibrium. That is, for every $S_i, S_j \in \kappa$, if $c_{S_i} \geq c_{S_j}$ then $e^*_{S_j} \geq e^*_{S_i}$ in the equilibrium.*

Proof. Observe that in a coalition structure equilibrium $e^* = (e^*_{S_1}, e^*_{S_2}, ...,$

$e^*_{S_m}$), the first-order condition leads to

$$c_{S_i} = \frac{e^*_{S_i}}{[e^*(\kappa)]^2}[f'(e^*(\kappa))e^*(\kappa) - f(e^*(\kappa))] + \frac{f(e^*(\kappa))}{e^*(\kappa)}, \tag{7}$$

for all $i \in \{1, 2, ..., m\}$, and $e^*(\kappa) = \sum_{i \in I(\kappa)} e^*_{S_i}$.

From (7), it follows that

$$c_{S_i} - c_{S_j} = \frac{e^*_{S_i} - e^*_{S_j}}{[e^*(\kappa)]^2}[f'(e^*(\kappa))e^*(\kappa) - f(e^*(\kappa))].$$

Moreover, assumption A1 implies that

$f'(e^*(\kappa))e^*(\kappa) - f(e^*(\kappa)) < 0$

in the equilibrium under κ.[10]
Therefore, if $c_{S_i} - c_{S_j} \geq 0$ we have $e^*_{S_i} \leq e^*_{S_j}$. ■

Summing up (7), it follows that total effort $e^*(\kappa)$ can be determined by the following equation:

$$f'(e^*(\kappa)) + (k-1)\frac{f(e^*(\kappa))}{e^*(\kappa)} = \sum_{j=1}^{k} c_{S_j}. \tag{8}$$

Furthermore, from (7) and (8),

$$e^*_{S_j} = \frac{e^*(\kappa)[c_{S_j} - \frac{f(e^*(\kappa))}{e^*(\kappa)}]}{f'(e^*(\kappa))e^*(\kappa) - f(e^*(\kappa))}$$

and

$$f'(e^*(\kappa))e^*(\kappa) - f(e^*(\kappa)) = \sum_{m=1}^{k} c_{S_m} - k\frac{f(e^*(\kappa))}{e^*(\kappa)}.$$

Then, for every coalition structure $\kappa = \{S_1, S_2, ..., S_k\}$,

$$e^*_{S_j} = e^*(\kappa)\left(\frac{\frac{f(e^*(\kappa))}{e^*(\kappa)} - c_{S_j}}{k\frac{f(e^*(\kappa))}{e^*(\kappa)} - \sum_{m=1}^{k} c_{S_m}}\right), \tag{9}$$

where $e^*(\kappa) = \sum_{j=1}^{k} e^*_{S_j}$, and $e^* = (e^*_{S_1}, e^*_{S_2}, ..., e^*_{S_k})$.

[10] Since $f(0) = 0$, and $f'(x)x - f(x)$ is decreasing and non-positive.

If the share of efforts of coalition S_j in the competitive equilibrium under structure κ is defined by $sh(S_j) = \frac{e^*_{S_j}}{e^*(\kappa)}$. Then from (9) it follows that

$$sh(S_j) = \frac{\frac{f(e^*(\kappa))}{e^*(\kappa)} - c_{S_j}}{k\frac{f(e^*(\kappa))}{e^*(\kappa)} - \sum_{m=1}^{k} c_{S_m}}. \tag{10}$$

The above equations (8) and (9) form an alternative to the proof of Proposition 3.1 and show how to calculate total effort and each coalition effort in coalition structures. Therefore, total effort can be predicted by the aggregate marginal cost and the number of coalitions k. In the following example we will illuminate how to calculate total effort and the effort of each coalition, under a given coalition structure in the competitive equilibrium.

Example 3.1 Consider four countries, indexed by $i = 1, 2, 3, 4$, with the production function $f(e_N) = (60 - e_N)e_N$ and marginal costs $c_1 = 2$, $c_2 = 3$, $c_3 = 6$, $c_4 = 9$. Aggregate marginal costs, total effort and total benefits as calculated by means of (8) and (9) are presented in Table 3.1.

coalitions	κ	$\sum_{m=1}^{k} c_{S_m}$	$e^*(\kappa)$	$\pi(e^*(\kappa))$
$k = 4$	$1 - 2 - 3 - 4$	20	44	514
$k = 3$	$12 - 3 - 4$	17	40.75	548.18
$k = 3$	$13 - 2 - 4$	14	41.50	602.75
$k = 3$	$1 - 23 - 4$	14	41.50	602.75
$k = 3$	$14 - 2 - 3$	11	42.25	603.68
$k = 3$	$1 - 24 - 3$	11	42.25	603.68
$k = 3$	$1 - 2 - 34$	11	42.25	603.68
$k = 2$	$123 - 4$	11	36.33	684.51
$k = 2$	$12 - 34$	8	37.33	704.81
$k = 2$	$124 - 3$	8	37.33	704.81
$k = 2$	$14 - 23$	5	38.33	735.71
$k = 2$	$13 - 24$	5	38.33	735.71
$k = 2$	$134 - 2$	5	38.33	735.71
$k = 2$	$1 - 234$	5	38.33	735.71
$k = 1$	1234	2	29	841

Table 3.1. *The possible coalition structures for the four countries.*

Consider, for example, the case $k = 3$ with $\kappa = \{12, 3, 4\}$. Aggregate marginal cost of this coalition structure is $2+6+9 = 17$.[11] Since $f'(e^*(\kappa)) =$

[11] Observe that transferable technology within a coalition is assumed.

$60 - 2e^*(\kappa)$ and $\frac{f(e^*(\kappa))}{e^*(\kappa)} = 60 - e^*(\kappa)$, equation (8) implies that

$$60 - 2e^*(\kappa) + 2[60 - e^*(\kappa)] = 17.$$

Solving the above equation, the total effort in the competitive equilibrium is obtained by $e^*(\kappa) = \frac{180-17}{4} = 40.75$.
Substituting $e^*(\kappa)$ into (9) we have

$e^*_{\{12\}} = 40.75\left(\frac{60-40.75-2}{3(60-40.75)-17}\right) = 17.25,$

$e^*_{\{3\}} = 40.75\left(\frac{60-40.75-6}{3(60-40.75)-17}\right) = 13.25,$ and

$e^*_{\{4\}} = 40.75\left(\frac{60-40.75-9}{3(60-40.75)-17}\right) = 10.25.$

Similarly for all other coalition structures.

Corollary 1 *For every coalition structure κ, the lower the marginal cost c_{S_i}, the higher the net benefits in the coalition structure equilibrium.*

Proof. Let $e^* = (e^*_{S_1}, e^*_{S_2}, ..., e^*_{S_m})$ be a coalition structure equilibrium. By Proposition 3.1 above, if $c_{S_i} \geq c_{S_j}$, then $e^*_{S_i} \leq e^*_{S_j}$. Moreover, at this equilibrium, the difference in payoffs between coalitions S_i and S_j is:

$\pi(S_i, \kappa) - \pi(S_j, \kappa) = \frac{f(e^*(\kappa))}{e^*(\kappa)}(e^*_{S_i} - e^*_{S_j}) - c_{S_i} \cdot e^*_{S_i} + c_{S_j} \cdot e^*_{S_j} =$

$$\frac{f(e^*(\kappa))}{e^*(\kappa)}(e^*_{S_i} - e^*_{S_j}) - c_{S_i}(e^*_{S_i} - e^*_{S_j}) + e^*_{S_j}(c_{S_j} - c_{S_i}) =$$

$$\underbrace{(\frac{f(e^*(\kappa))}{e^*(\kappa)} - c_{S_i})}_{(+)}\underbrace{(e^*_{S_i} - e^*_{S_j})}_{(-)} + e^*_{S_j}\underbrace{(c_{S_j} - c_{S_i})}_{(-)}.$$

Since in the competitive equilibrium $\frac{f(e^*(\kappa))}{e^*(\kappa)} \geq c_{S_i}$ (i.e. by (7)), it follows that $\pi(S_i, \kappa) - \pi(S_j, \kappa) \leq 0$. ■

Proposition 3.2 *Let κ and κ' be two coalition structures of a game $(N, w) \in FGPFF^N$, where κ is formed by values c_{S_j}, $S_j \in \kappa$ and κ' is formed by $c_{S'_j}$, $S'_j \in \kappa'$, and $|\kappa| \geq |\kappa'|$. Then $e^*(\kappa) \geq e^*(\kappa')$ if $\sum_{j=1}^{k} c_{S_j} \leq \sum_{j=1}^{m} c_{S'_j}$.*

Proof. Let $|\kappa| = k$, $|\kappa'| = m$, and $k \geq m > 1$. Since $\sum_{j=1}^{k} c_{S_j} \leq \sum_{j=1}^{m} c_{S'_j}$ and (8), it follows that

$f'(e^*(\kappa)) + (k-1)\frac{f(e^*(\kappa))}{e^*(\kappa)} \leq f'(e^*(\kappa')) + (m-1)\frac{f(e^*(\kappa'))}{e^*(\kappa')}$. Hence

$$f'(e^*(\kappa))-f'(e^*(\kappa'))+(m-1)[\tfrac{f(e^*(\kappa))}{e^*(\kappa)}-\tfrac{f(e^*(\kappa'))}{e^*(\kappa')}]+(k-m)\tfrac{f(e^*(\kappa))}{e^*(\kappa)} \leq 0. \qquad (\star)$$

Assume to the contrary that $e^*(\kappa) < e^*(\kappa')$. Since $\frac{f(x)}{x}$ and $f'(x)$ are decreasing functions, it follows that

$$f'(e^*(\kappa)) > f'(e^*(\kappa')) \text{ and } \tfrac{f(e^*(\kappa))}{e^*(\kappa)} > \tfrac{f(e^*(\kappa'))}{e^*(\kappa')}.$$

oreover, $k - m \geq 0$. Therefore the left hand side of inequation $(\star)$ is positive which is a contradiction. ■

This Proposition shows that total fishing effort for a coalition structure depends on the number of coalitions and aggregate marginal cost in the competitive equilibrium. However, for a given coalition structure, the forming of coalitions with lower total cost need not reduce the total effort, while for a given total cost, the total effort increases if the number of coalitions increases (i.e. if $\sum_{S\in\kappa} c_S = c(\kappa) = c(\kappa')$, and $|\kappa| > |\kappa'|$, then $e^*(\kappa) > e^*(\kappa')$).[12] These results are illuminated in Table 3.1:

(i) coalition structures $\{14, 2, 3\}$ and $\{123, 4\}$ have the same aggregate marginal cost, i.e. 11, but $e(3, \{14, 2, 3\}) > e(2, \{123, 4\})$.
(ii) coalition structures $\{123, 4\}$ and $\{124, 3\}$ have the same number of coalitions, i.e. $k = 2$, but aggregate marginal cost is 11 for $\{123, 4\}$ which is larger than aggregate marginal cost 8 for $\{124, 3\}$. Then the total effort $e(2, \{123, 4\}) < e(2, \{124, 3\})$.

Applying (6), the partition function form game (N, w) is obtained as follows

$$\overline{\pi}(1, 2, 3, 4) = (196, 169, 100, 49);$$

$$\begin{array}{l}\overline{\pi}(12, 3, 4) = (297.56, 175.56, 105.06);\\ \overline{\pi}(13, 2, 4) = \overline{\pi}(1, 23, 4) = (272.25, 240.25, 90.25);\\ \overline{\pi}(14, 2, 3) = \overline{\pi}(1, 24, 3) = \overline{\pi}(1, 2, 34) = (248.06, 217.56, 138.06);\end{array} \qquad (G3.1)$$

$$\overline{\pi}(123, 4) = (469.59, 214.92);$$

[12] These results imply that the forming of coalitions will determine the situation of a fish stock. Moreover, aggregate effort under a given coalition structure depends strongly upon how coalitions are formed by the marginal costs. For a given number of coalitions, the coalition structure with lower aggregate marginal cost has higher total effort.

$\overline{\pi}(124,3) = \overline{\pi}(12,34) = (427.25, 277.56)$;

$\overline{\pi}(1,234) = \overline{\pi}(13,24) = \overline{\pi}(14,23) = \overline{\pi}(134,2) = (386.91, 348.20)$;

$\overline{\pi}(1234) = 841$.

From this partition function, it follows that for the case of $k = 3$ coalition structure $\{14,2,3\}$ is the only feasible[13], while every coalition structure consisting of two coalitions is feasible.

Observe that if countries are identical, i.e. $c_i = c_j$ for all $i \neq j$, the equations (8) and (9) in the unique equilibrium $e^* = (e^*_{S_i}, e^*_{S_2}, ...e^*_{S_m})$ under κ satisfy:

$f'(e^*(\kappa)) + (k-1)\frac{f(e^*(\kappa))}{e^*(\kappa)} = k \cdot c$,

$e^*_{S_j} = \frac{e^*(\kappa)}{k} > 0$, for all $j = 1,2,...,k$, where $e^*(\kappa) = \sum_{j=1}^{k} e^*_{S_j}$.

Therefore, the effort of each coalition only depends on the number k of coalitions. Furthermore, for any coalition structure $\kappa = \{S_1, S_2, ..., S_k\}$, total fishing effort is an increasing function of the number of coalitions k, whereas total net rents and the net rent of each coalition are decreasing functions of k (Theorem 2 in Funaki and Yamato, 1999).[14]

Corollary 2 *For the case of identical countries, it follows that*
(i) the minimum and maximum value of a coalition $S \subseteq N$ are determined by

$$\begin{aligned} \min_{\kappa: S \in \kappa} \pi(S,\kappa) &= \pi(S, S \cup [N \backslash S]), \\ \max_{\kappa: S \in \kappa} \pi(S,\kappa) &= \pi(S, S \cup \{N \backslash S\}). \end{aligned}$$

(ii) a coalition structure κ is feasible if the size of the largest coalition is feasible under the equal sharing rule.

Proof. (i) We have $\min \pi(S,\kappa) \leq \pi(S,\kappa') \leq \max_{\kappa: S \in \kappa} \pi(S,\kappa)$ for all coalition structures $\kappa' \neq \kappa$. Moreover, from Proposition 3.2, i.e. that fishing

[13] This is because $\pi(14,\{14,2,3\}) = 248.06 > \pi(1,[N]) + \pi(4,[N]) = 245$, $\pi(2,\{14,2,3\}) > \pi(2,[N])$ and $\pi(3,\{14,2,3\}) > \pi(3,[N])$.

[14] This result can be easily extended to the asymmetric case such as a refinement of the coalition structure: for a given coalition structure, the broken coalition will increase both total cost and total effort (related to the original coalition structure).

effort is an increasing function of the number of coalitions, it follows that for any two coalition structures $\kappa = \{S_1, S_2, ...S_k\}$ and $\kappa' = \{S'_1, S'_2, ...S'_m\}$ such that $k < m$, $e^*(\kappa) < e^*(\kappa')$; $\pi(e^*(\kappa)) > \pi(e^*(\kappa'))$;and if $S \in \kappa$ and $S \in \kappa'$

$$\pi(S, \kappa) > \pi(S, \kappa')$$

where $e^*(\kappa) = \sum_{j=1}^{k} e^*_{S_j}$, $e^*(\kappa') = \sum_{i=1}^{m} e^*_{S_i}$. Thus, result (i) is obtained.

(ii) In a Nash equilibrium, e^*, the net benefits are:
$\pi(i, [N]) = \frac{[f(e^*_N) - c \cdot e^*_N]}{n}$ for all $i \in N$, and $\sum_{i \in S} \pi(i, [N]) = \frac{|S|[f(e^*_N) - c \cdot e^*_N]}{n}$.

Then, if countries have prudent perceptions (pessimistic expectations), a vector $z = (z_1, z_2, ..., z_n)$ can be considered as a feasible payoff if

$$\sum_{j \in S} z_j \geq \frac{|S|[f(e^*_N) - c \cdot e^*_N]}{n}.$$

We observe that for a given coalition structure κ with k coalitions, a vector z is a feasible payoff vector if $z_j = \frac{c \cdot e^*(\kappa) - f(e^*(\kappa))}{|S|k} \geq \frac{[f(e^*_N) - c \cdot e^*_N]}{n}$ for all $j \in S$, where $e^*(\kappa)$ is the total effort in an equilibrium under κ, and e^*_N is the Nash equilibrium. Since $\pi(S, \kappa) = \frac{f(e^*(\kappa)) - c \cdot e^*(\kappa)}{k}$ for all $S \in \kappa$, then, if $\frac{f(e^*(\kappa)) - c \cdot e^*(\kappa)}{k|S_m|} \geq \frac{f(e^*_N) - c \cdot e^*_N}{n}$ for the coalition S_m, where $|S_m| = \max_{j \in I(\kappa)} |S_j|$, it follows that

$$\frac{f(e^*(\kappa)) - c \cdot e^*(\kappa)}{k|S_j|} \geq \frac{f(e^*(\kappa)) - c \cdot e^*(\kappa)}{k|S_m|} \geq \frac{f(e^*_N) - c \cdot e^*_N}{n} \text{ for all } S_j \in \kappa. \qquad \blacksquare$$

Example 3.2 Consider four identical countries, $i = 1, 2, 3, 4$, with marginal cost $c = 9$ and production function $f(e) = (60 - e)e$. Since all countries are identical, there are only five types of coalition structures: $\kappa_1 = \{|1|, |1|, |1|, |1|\}$, $\kappa_2 = \{|1|, |1|, |2|\}$, $\kappa_3 = \{|2|, |2|\}$, $\kappa_4 = \{|1|, |3|\}$, and $\kappa_5 = \{|4|\}$, where $|i|$ denotes the number of countries. The game $(N, \pi) \in FGPFF^N$ is given by

$\overline{\pi}(|1|, |1|, |1|, |1|) = (100.40, 100.40, 100.40, 100.40)$;
$\overline{\pi}(|1|, |1|, |2|) = (162.56, 162.56, 162.56)$;
$\overline{\pi}(|2|, |2|) = \overline{\pi}(|1|, |3|) = (289, 289)$; $\overline{\pi}(|4|) = 650.25$.

The coalition structures κ_3 is feasible, since

$$\pi(|2|, \kappa_3) = 289 > 2 \cdot \pi(|1|, \kappa_1) = 200.80,$$

under the equal sharing rule. However, a coalition with 2 players for a coalition structure consisting of 3 coalitions is not feasible since $\pi(|2|, \kappa_2) = 162.56 < 2 \cdot \pi(|1|, \kappa_1) = 200.80$.

4 Distribution of payoffs

This section considers the distribution of payoffs of partial cooperation that countries can agree upon. To simplify the analyses, suppose the production function takes the quadratic form $f(e) = (b-e)e$. The parameter b can be considered a critical (maximum) effort level where production cannot recover the total cost, i.e. $f(e_N) \leq c \cdot e_N$ if $e_N \geq b$, and $c \in [\min_{i\in N} c_i, \max_{i\in N} c_i]$.

Recall that $c_1 \leq c_2 \leq ... \leq c_n$. To ensure that all countries have the possibility to catch, i.e. $e_j^* \geq 0$ for all $j \in N$, we assume that $\frac{b+\sum_{j=1}^n c_j}{n+1} > c_n$.[15] The net benefit function of coalition S_i under coalition structure κ is:

$$\pi_{S_i}(e_{S_i}, e_{-S_i}) = (b - e_N)e_{S_i} - c_{S_i} \cdot e_{S_i}. \tag{11}$$

For each coalition structure κ, the value $\pi_{S_i}(e^*_{S_i}, e^*_{-S_i})$ of the coalition S_i (under κ) is defined by (11) at competitive equilibrium e^*. Denote the share of efforts of coalition S in the competitive equilibrium e^* under structure κ as $sh(S) = \frac{e^*_S}{e^*(\kappa)}$, where $e^*(\kappa) = \sum_{S\in\kappa} e^*_S$ and $e^*_S = \sum_{l\in S} e^*_l$. Moreover, let $\pi(e^*(\kappa)) = \sum_{S\in\kappa} \pi_S(e^*)$ be the total net benefit.

Proposition 4.1 *For every coalition structure κ, the following results hold for every competitive equilibrium*

(i) *for any $i < j$, $c_{S_j} - c_{S_i} = e^*_{S_i} - e^*_{S_j} \geq 0$*

(ii) $\frac{\partial e^*_{Si}}{\partial c_{S_j}} = \begin{cases} -\frac{k}{k+1} < 0 & \text{if } i = j \\ \frac{1}{k+1} > 0 & \text{if } i \neq j \end{cases}$

(iii) $\frac{\partial \pi_{S_j}(.)}{\partial c_{S_i}} = \begin{cases} -\frac{2k}{k+1} e^*_{S_j} < 0 & \text{if } i = j \\ \frac{2}{k+1} e^*_{S_j} > 0 & \text{if } i \neq j \end{cases}$

(iv) $\frac{\partial \pi(e^*(\kappa))}{\partial c_{S_j}} > 0 \Longleftrightarrow sh(S_j) < 1/(k+1)$

Proof. (i) From (7) and $f(e^*) = (b-e^*)e^*$ which implies (i).

(ii) Since $e^*_N = (kb - \sum_{i=1}^k c_{S_i})/(k+1)$ and $e^*_{S_i} = (b - e^*_N) - c_{S_j}$ it follows that

$$e^*_{S_i} = \frac{b - kc_{S_i} + \sum_{j\neq i} c_{S_j}}{k+1}$$

leading to (ii).

(iii) As $\pi_{S_j}(e^*) = (b - e^*_N - c_{S_j})e^*_{S_j} = (e^*_{S_j})^2$, it follows that

[15] This assumption is considered as the requirement of positive shares at the equilibrium for all players (for details, see Zhao, 2001).

$$\frac{\partial \pi_{S_j}(e^*)}{\partial c_{S_i}} = 2e^*_{S_j}\frac{\partial e^*_{Sj}}{\partial c_{S_i}} = \begin{cases} -\frac{2k}{k+1}e^*_{S_j} < 0 & if\ i = j \\ \frac{2}{k+1}e^*_{S_j} > 0 & if\ i \neq j \end{cases} .$$

leading to (iii).

(iv) Since $\pi(e^*(\kappa)) = \sum_{j=1}^{k} \pi_{S_j}(e^*)$ and (iii), it follows that

$$\frac{\partial \pi(e^*(\kappa))}{\partial c_{S_i}} = \sum_{j=1}^{k} \frac{\partial \pi_{S_j}(e^*)}{\partial c_{S_i}} = \frac{\partial \pi_{S_i}(e^*)}{\partial c_{S_i}} + \sum_{j \neq i} \frac{\partial \pi_{S_j}(e^*)}{\partial c_{S_i}}$$

$$= 2[\frac{-k}{k+1}e^*_{S_i} + \frac{1}{k+1}\sum_{j \neq i} e^*_{S_j}] = \frac{2}{k+1}\{-ke^*_{S_i} + [\sum_{m=1}^{k} e^*_{S_m} - e^*_{S_i}]\}$$

$$= \frac{2\sum_{m=1}^{k} e^*_{S_m}}{k+1}[1 - \frac{(k+1)e^*_{S_i}}{\sum_{m=1}^{k} e^*_{S_m}}] > 0 \Leftrightarrow 1 - \frac{(k+1)e^*_{S_i}}{\sum_{m=1}^{k} e^*_{S_m}} > 0$$

$\Leftrightarrow sh(S_i) < \frac{1}{k+1}$, which implies (iv). ■

Proposition 4.1 shows the relationship between marginal costs, fishing efforts and net benefits for coalitions in the competitive equilibrium[16]. To illuminate Proposition 4.1 consider a coalition structure κ consisting of k coalitions ($|\kappa| = k$) and the case where one member i leaves its coalition $S_{\kappa(i)}$ ($\in \kappa$) and joins another coalition, say $S_{\kappa(j)} \in \kappa$. If the marginal cost c_i of this member is larger than the marginal cost $c_{S_{\kappa(i)}}$ of its former coalition $S_{\kappa(i)}$ but smaller than the cost $c_{S_{\kappa(j)}}$ of its new coalition $S_{\kappa(j)}$, then the joining of this member will lead to a cost reduction of coalition $S_{\kappa(j)}$. Moreover, the marginal cost of the coalition to which i used to belong does not change. Therefore, although the number of a new coalition structure κ' does not change (i.e. $|\kappa'| = k$, since only i changes coalitions), the cost structure does change. In similar vein, (ii) and (iii) describe the impacts on coalition efforts and coalition net benefits. If own marginal costs of a coalition increase, own efforts and net benefits decrease, whereas if the marginal costs of another coalition increase own efforts and net benefits increase. According to (iv), the forming of a new coalition structure may cause a reduction of total net benefit if at least one of the effort shares is larger than $\frac{1}{k+1}$.

The above Propositions 3.1, 3.2 and 4.1 imply that although an outcome depends on both the marginal cost c_{S_j} and cardinality of κ, countries with high costs have an incentive to cooperate since they will take advantage by reducing costs when joining a coalition with lower costs. The following example illuminates this.

Example 4.1 Consider Example 3.1. The benefits of free-riding for each coalition structure are presented in Table 4.1. The number of coalitions

[16] Coalitions mean both individuals and groups of individuals in a given coalition structure.

is presented in the first column and the benefit of each free-rider follows in the next columns.

In Table 4.1 the second row represents noncooperative net benefits. The third and fourth rows represent free riding benefits for countries i, j, $i \neq j$ when countries k and l form a coalition $\{kl\}$, $k, l \in N\backslash\{i, j\}$. For example, for $k = 3$, 272.25 and 248.06 are the payoffs of country 1 in the coalition structures $\kappa = \{1, 4, 23\}$ with aggregate marginal cost 14 and $\kappa = \{1, 3, 24\}$ with aggregate marginal cost 11, respectively (see Table 3.1). The last row represents free riding benefits for country i when $N\backslash\{i\}$ forms a coalition.

$\lvert\kappa\rvert$	$\pi(\{1\}, \kappa)$	$\pi(\{2\}, \kappa)$	$\pi(\{3\}, \kappa)$	$\pi(\{4\}, \kappa)$
$k = 4$	196	169	100	49
$k = 3$ (free-riders with high costs)	272.25	240.25	175.56	105.06
$k = 3$ (free-riders with low costs)	248.06	217.56	138.06	90.25
$k = 2$	386.91	348.20	277.56	214.92

Table 4.1 *The benefits of free-riding.*

If only two countries form a coalition (i.e. $k = 3$) then, relative to the noncooperative situation a free-rider country, for example, country 4, gains $90.25 - 49 = 41.25$ (84%) in the low cost cases (i.e. coalition structures $\{13, 2, 4\}$ or $\{1, 23, 4\}$), and $105.06 - 49 = 56.06$ (114%) in the high cost case (i.e. coalition structure $\{12, 3, 4\}$). In a similar vein, country 1 gains $248.06 - 196 = 52.06$ (27%) in coalition structure $\{1, 24, 3\}$ and $272.25 - 196 = 76.25$ (39%) in coalition structure $\{1, 23, 4\}$.

In Example 4.1, although country 4 with the highest marginal cost has the smallest net benefit in the noncooperative situation (Corollary 3.1), it will gain relatively more from free-riding than the other countries. For example, consider the case of only one free-rider (i.e. $k = 2$). In this situation, if countries 1,2 and 3 form a coalition $\{123\}$, then in the coalition structure $\{123, 4\}$ country 4 gains $214.92 - 49 = 165.92$ (337%). The gains are 177.56 (177%) in $\{124, 3\}$ for country 3, 179.20 (106%) in $\{134, 2\}$ for country 2 and 190.91 (97%) for country 1 in $\{234, 1\}$. Moreover, in coalition structure $\{123, 4\}$ country 4 gains more than in coalitions with two free-riders (c.f. $\{1, 4, 23\}$ or $\{13, 2, 4\}$ with gains 56.06 (114%) and $\{12, 3, 4\}$ with gains 41.25 (84%) for country 4).

Observe that although all coalition structures with two coalitions in Example 4.1 are feasible under the equal sharing rule (see section 3), the total

benefits of coalition structures with two coalitions will increase if country 4 forms a coalition such that the lowest cost coalition materializes (because it reduces the total cost of the coalition structure). For example, consider $\kappa_1 = \{12, 34\}$, $\kappa_2 = \{14, 23\}$, $\kappa_3 = \{13, 24\}$, $\kappa_4 = \{123, 4\}$, $\kappa_5 = \{124, 3\}$, $\kappa_6 = \{134, 2\}$ and $\kappa_7 = \{234, 1\}$. From the last column in Table 3.1, it follows that[17]:
$\pi(e^*(2, \kappa_2)) = 735.71 > 704.81 = \pi(e^*(2, \kappa_1))$, and
$\pi(e^*(2, \kappa_7)) = 735.71 > 704.81 = \pi(e^*(2, \kappa_5)) > 648.51 = \pi(e^*(2, \kappa_4))$.

In coalition structures κ_4, κ_5, κ_6 and κ_7 there is free-riding by countries $4, 3, 2$ and 1, respectively[18]. The total effort and total net benefit are affected by the marginal cost of the free-rider. For example, Table 3.1 shows that if country 1 or 2 free-rides, then total effort is 38.33 and the total net benefit is 735.71. If country 3 free-rides, then the total effort is 37.33 and the total net benefit is 704.81, whereas the total effort reduces to 36.33 and total net benefit is 684.51 if country 4 free-rides.

The smallest effort (29) and highest net benefit (841) materialize for the grand coalition only. Therefore, although there exist some feasible partial coalition structures, the grand coalition is optimal efficiency.

The question arises what sharing rule of the net benefits should be adopted to stimulate the fishing nations to join the grand coalition. We propose the modified Shapley value, developed by Pham Do and Norde (2002).[19] The reason to consider the modified Shapley value rather than the original value developed by Shapley[20] (1953) is that, the latter cannot be applied to games in partition function form such as the present game $(N, w) \in PFFG^N$, since in this class of games the contributions of each player to the grand coalition differ among coalition structures, due to the presence of externalities among coalitions.

Pham Do and Norde (2002) show that the modified Shapley value (see Appendix) is a unique and efficient solution for a $PFFG^N$. Moreover, they point out that for a class of oligopoly games in partition function form such as a $(N, w) \in FGPFF^N$, where the net benefit function (11) is determined in a competitive equilibrium under coalition structures, the modified Shap-

[17] Note that $\pi(e^*(2, \kappa_2)) = \pi(e^*(2, \kappa_3))$ and $\pi(e^*(2, \kappa_7)) = \pi(e^*(2, \kappa_6))$ since the total cost of κ_2 and κ_3 as well as κ_7 and κ_6 are equal.

[18] It is a reason why the full cooperation may not stable if a distribution of benefits can not be accepted by several countries.

[19] An alternative is the equal sharing rule. However, this rule does not take into account the contributions of each player to the grand cooperation, whereas the Shapley value does.

[20] For the introduction to the Shapley value, its extensions and applications, see, for example, chapters 53-58 in Aumann and Hart (2002).

ley value keeps the same ordering for every player in the Nash situation. Applying this result to a fishery game in partition function form, the following proposition is obtained.

Proposition 4.2 *Let ψ be the modified Shapley value for a $(N,\pi) \in FGPFF^N$, where the net benefit function (11) is determined in a competitive equilibrium under coalition structures. It follows that if $c_1 \leq c_2 \leq ... \leq c_n$ then*

(i) $\pi(1,[N]) \geq \pi(2,[N]) \geq ... \geq \pi(n,[N])$,

(ii) $\psi_1(\pi) \geq \psi_2(\pi) \geq ... \geq \psi_n(\pi)$, and

(iii) $\pi(N,\{N\}) = \sum_{i=1}^{n} \psi_i(\pi)$.

Proof. See section 6 in Phamdo and Norde (2002). ■

It is obvious that stable cooperation result if $\psi_i(\pi) \geq \pi(i,[N])$ for every $i \in N$.

Example 4.2 Consider the fishery game in partition function form (N,π) in Example 3.1, where w is given by $(G3.1)$. In this game, we have

$$\pi(1,[N]) = 196 > \pi(2,[N]) = 169 > \pi(3,[N]) = 100 > \pi(4,[N]) = 49.$$

Using the Appendix the modified Shapley value is obtained as

$$\psi(\pi) = (271.18, 238.86, 184.94, 146.02).$$

Additionally, $\pi(4,\{4\}) = \sum_{i=1}^{4} \psi_i(\pi) = 841$.

The modified Shapley value allocates the payoffs such that the contributions of each country in the grand coalition as determined by its marginal cost are rewarded. The surplus gained from full cooperation is $(75.18, 69.86, 84.94, 97.02)$. Each country has thus a different gain in the grand cooperation, due to its contribution. We observe that this distribution differs from the values that are obtained by applying other division rules such as the equal sharing rule. For example, the transition from the noncooperative to the cooperative situation yields the surplus 327 $(= 841 - 514)$. The equal sharing rule gives the outcomes $(277.75, 250.75, 181.75, 130.75)$, where each player gains 81.75.

This example indicates that although the equal sharing rule can be applied for any feasible coalition structure, the modified Shapley value has more potential to induce full cooperation.

Finally, we observe that although each country is better off in the grand coalition than in the competitive outcome, individual countries can do even better by free riding under certain circumstances, as illustrated in the last row of Table 4.1. This implies that application of the modified Shapley value is not sufficient to discourage free riding. Therefor, additional measures are needed to deter free riding; e.g. linking a fishery problem to another problem in which the players are involved (see Folmer et al., 1993 and Kroeze-Gil, 2003 and the references therein).

5 Concluding remarks

The objective of regional fishery agreements is to develop rules for joint decision making to use common fishery resources efficiently to avoid inefficient outcomes, and the collapse of fish stocks resulting from noncooperative behaviour. Furthermore, a better balance must be reached between fishing effort and the quantities of fish that can be removed from the sea without endangering the future of the fish stocks or ecosystems.

This paper has addressed the formation of coalitions smaller than the grand coalition. Particularly, attention has been paid to the feasibility of coalition structures and their impacts on reducing harvest levels. We have shown that for every coalition structure in a competitive equilibrium a coalition with lower marginal cost has a higher effort level, and total fishing effort is an increasing function of the number of coalitions. Moreover, the lower the marginal costs, the higher the net benefits in the coalition structures.

In order to induce countries to cooperate the modified Shapley value adopted to games in partition function form has been considered. This is a unique and efficient division rule of gains from cooperation that preserves the ordering of players in the Nash outcome. This device can be applied to develop a profit allocation scheme such as a reasonable compromise and compensation for both the potential entrants and the charter members. However, allocation of the gains from cooperation on the basic of the modified Shapley value is not sufficient to discourage free-riding since under certain coalition structures the latter option may result in a higher payoff than is attainable on the basic of the modified Shapley value.

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Appendix

In order to introduce the modified Shapley value for games in partition function form, we need some additional notations. Let $\Pi(N)$ be the set of all *bijections* $\sigma : \{1, 2, ..., n\} \to N$ of N. For a given $\sigma \in \Pi(N)$ and $i \in I([N])$ we define $S_i^\sigma = \{\sigma(1), \sigma(2), ..., \sigma(i)\}$, and $S_0^\sigma = \emptyset$. For a given $\sigma \in \Pi(N)$ and $i \in I([N])$, we define the partition κ_i^σ associated with σ and i, by $\kappa_i^\sigma = \{S_i^\sigma\} \cup [N \backslash S_i^\sigma]$. So, in κ_i^σ the coalition S_i^σ has already formed, whereas all other players still form singleton coalitions. Furthermore, we define $\kappa_0^\sigma = [N]$.

Let (N, w) be a partition function form game, and $\sigma \in \Pi(N)$. We define the marginal contribution of the i^{th} player $\sigma(i)$ to coalition S_i^σ such as

$$m_{\sigma(i)}^\sigma(w) := w(S_i^\sigma, \kappa_i^\sigma) - w(S_{i-1}^\sigma, \kappa_{i-1}^\sigma).$$

Based on these marginal vectors $\{m^\sigma(w)\}_{\sigma \in \pi(N)}$, we define the modified *Shapley value* ψ of the partition function form game (N,w) as the average of the $n!$ marginal vectors[21],

$$\psi(w) = \frac{1}{n!} \sum_{\sigma \in \Pi(N)} m^\sigma(w).^{22}$$

Example Consider the partition function form game (N, w) defined by

$\overline{w}(1, 2, 3) = (0, 0, 0)$, $\overline{w}(12, 3) = (2, 0)$, $\overline{w}(23, 1) = (3, 2)$, $\overline{w}(13, 2) = (2, 1)$, $\overline{w}(123) = 10$.

The marginal vectors associate[23] with σ are:

$$\text{if} \quad \sigma_1 = (1, 2, 3) \text{ then } m^{\sigma_1}(w) = (0, 2, 8)$$

$$\text{if} \quad \sigma_2 = (2, 1, 3) \text{ then } m^{\sigma_2}(w) = (2, 0, 8)$$

$$\text{if} \quad \sigma_3 = (1, 3, 2) \text{ then } m^{\sigma_3}(w) = (0, 8, 2)$$

[21] Further details, see Pham Do and Norde (2002).

[22] Observe the similarity to TU-games (c.f. Shapley, 1953).

[23] For example, the marginal vector of σ_2 is computed as follows. As $\sigma_2 = (2, 1, 3)$ then $m_{\sigma_2(1)}^{\sigma_2}(w) = w(21, \{21, 3\}) - w(2, [N]) = 2$, $m_{\sigma_2(2)}^{\sigma_2}(w) = w(2, [N]) = 0$, $m_{\sigma_2(3)}^{\sigma_2}(w) = w(213, \{N\}) - w(21, \{21, 3\}) = 10 - 2 = 8$. Hence, $m^{\sigma_2}(w) = (2, 0, 8)$.

$$\text{if} \quad \sigma_4 = (2,3,1) \text{ then } m^{\sigma_4}(w) = (7,0,3)$$

$$\text{if} \quad \sigma_5 = (3,1,2) \text{ then } m^{\sigma_5}(w) = (2,8,0)$$

$$\text{if} \quad \sigma_6 = (3,2,1) \text{ then } m^{\sigma_6}(w) = (7,3,0).$$

So, the modified Shapley value $\psi(w) = (3, 3.5, 3.5)$.