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FREE RIDING PROBLEMS AND FEASIBLE ALLOCATIONS FOR REGIONAL FISHERY MANAGEMENT ORGANIZATIONS

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Abstract This paper analyzes the free riding problem from a game theoretic point of view. The feasible proportional allocation rules for a special class of free riding problems are studied. Some key practical and theoretical properties of these rules are developed that can be used to stimulate cooperation and to discourage free riding behaviors. Applications to the management of the Baltic Sea cod fishery and the Norwegian herring fishery are presented.

Key Words: games with externalities, feasible allocations, free riding problems, regional fisheries management.

Subject Classification: 91A40, 91A80, 91B76, 91B08.

1 Introduction

Free riding is a situation where players (e.g. individuals or organizations) benefit from the actions and efforts of others without contributing to the costs incurred in generating the benefits. Typical situations where free rider problems occur in the international arena are abatement of global warming and of ozone layer depletion and prevention of over fishing of the high seas.

Free riding can be seen as a prisoner's dilemma. Common resource management problems such as of high sea fish stocks may take this form. Consider one of the main problems for high sea fisheries, the new-entrants problem into a fishery. The 1995 UN conservation and management of straddling fish stocks and high migratory fish stocks agreement (UNFSA) allows any nation to fish outside the Exclusive Economic Zone. Although the agreement also mandates that a Regional Fishery Management Organization (RFMO) should handle the management of the fish stock, distant water fishing nations (DWFNs) may decide not to join a RFMO, but rather to harvest in an individually optimal fashion (Bjordal and Munro, 2003). This creates an incentive for all fishers/fishing nations not to join the RFMO and for incumbents to leave it, essentially bringing us back to the tragedy of the commons (Hardin, 1968).

To resolve this issue the RFMO must provide incentives to potential entrants that are considered fair and beneficial to both the existing participants and the new entrants. This paper discusses two proportional allocation rules to deal with the free rider problem of high seas fisheries resources. The paper also analyzes the feasible sets of the coalitions, their values and how application of the rules[1] may mitigate the free rider problem. Assuming that the players can freely merge or break apart and are farsighted[2] , we formulate a free rider problem as a game in partition function form (Thrall and Lucas, 1963) and apply the notion of proportional allocation (Phamdo, 2005) as a solution concept.

Our approach is an extension of the work by Phamdo and Folmer (2006) and Kronbak and Lindroos (2005) in a search for fair solutions to avoid free rider behaviour in RFMOs. Although the modified Shapley value (Phamdo and Norde, 2002) used by Phamdo and Folmer (2006) and the satisfactory nucleolus used by Kronbak and Lindoos (2005), can be considered as "fair" sharing rules for distributing the total positive gains from the grand coalition and stimulating the players to join the grand coalition, they are not sufficient to discourage free-riding, since under certain coalition structures the latter option may result in a higher payoff (see Phamdo and Folmer, 2006 and section 4 of this paper).

The next section presents some basic concepts of games in partition function form and introduces the notion of free rider games. Section 3 deals with feasible allocations and their properties for free rider games. Section 4 presents the application to fishery management. Concluding remarks follow in the last section.

[1] Proportional allocation is not a new idea but it "is deeply rooted in law and custom as a norm of distributed justice" (Young, 1994).

[2] That is, it is the final and not the immediate payoffs that matter to the coalitions (Chander, 2003).

2 Preliminaries

This section provides some notations and the basic concepts that will be used in the rest of the paper.

Let $N = \{1, 2, ..., n\}$ be a finite set of players. A non-empty set $S \subset N$ is called a coalition. A coalition structure κ on N is a partition of N into disjoint coalitions, i.e. $\kappa = \{S_1, S_2, ..., S_m\}$, $S_j \cap S_k = \varnothing$, for $j \neq k$ and $\cup_{k=1}^{m} S_k = N$. Let $\mathcal{P}(N)$ be the set of all partitions of N.

A partition of a subset $S \subset N$ is denoted by κ_S. The *grand coalition* is denoted by $\{N\}$; a singleton coalition denoted by $\{i\}$, and the coalition structure consists of all *singleton coalitions* denoted by $[N]$. We also denote $|S|$ as the number of players in S and $|\kappa|$ as the number of coalitions in κ.

Let $S(\kappa, i)$ be the coalition in κ to which player i belongs.

For $i \in N$ and $\kappa \in \mathcal{P}(N)$, a coalition structure arranged by *affiliating* $S(i, \kappa)$ to $T \in \kappa$, $\kappa_{+i}(T)$, is defined as follows:

$$\kappa_{+i}(T) = \{(\kappa \backslash \{S, T\}) \cup (S \backslash \{i\}) \cup (T \cup \{i\})\}. \tag{1}$$

A coalition structure $\kappa_{+i}(T)$ is simply a merge of player i into S, so a number of coalitions does not increase, i.e $|\kappa| \geq |\kappa_{+i}(T)|$.

A coalition structure $\kappa_{-i}(T)$ arranged by *withdrawing* i from S is defined as follows:

$$\kappa_{-i}(S) = \{(\kappa \backslash S) \cup \{i\} \cup (S \backslash \{i\})\} \tag{2}$$

A coalition structure $\kappa_{-i}(S)$ is simply a split of player i from S, so a number of coalitions will increase, i.e $|\kappa_{-i}(S)| > |\kappa|$.

For convenient use, we denote $\kappa_i(\varnothing)$ a coalition structure where player i plays as a singleton, i.e. $\kappa_i(\varnothing) = \{\{i\}, \kappa_{N \backslash i}\}$[3].

Let $E(N)$ denote the set of all embedded coalitions[4].

A *game in partition function form* is given by a pair (N, w), where N is a set of player and $w : E(N) \longrightarrow \mathcal{R}$ is a function associating a real number with each embedded coalition[5]. Throughout this paper the set of players N remains fixed and we will identify a partition function form game with its partition function. So we will write w instead of (N, w).

Let $\Gamma(N)$ be the set of partition function form games with player set N.

Definition 2.1 *A free rider game is a partition function game $w \in \Gamma(N)$ satisfying the following conditions:*

[3]**Example 2.1** Consider the coalition structure $\kappa = \{123, 45\}$. For $i = 1, T = \{123\}$ and $S = \{45\}$, then $\kappa_{+1}(S) = \{23, 145\}$, $\kappa_{-1}(T) = \{1, 23, 45\}$, and $\kappa_1(\varnothing)$ can be one of the following coalitions $\{1, 23, 45\}$, $\{1, 25, 34\}$, $\{1, 24, 35\}$, $\{1, 2345\}$, $\{1, 2, 345\}$, $\{1, 3, 245\}$, $\{1, 4, 235\}$, $\{1, 5, 234\}$, $\{1, 23, 4, 5\}$, $\{1, 2, 34, 5\}$ $\{1, 24, 3, 5\}$, $\{1, 25, 3, 4\}$, $\{1, 35, 2, 4\}$, $\{1, 2, 3, 45\}$, $\{1, 2, 3, 4, 5\}$.

[4]An embedded coalition specifies the coalition as well as the structure of coalition formed by the other players, i.e. $E(N) = \{(S, \kappa) \in 2^N \times \mathcal{P}(N) |\ S \in \kappa\}$.

[5]the value $w(S, \kappa)$ represents the payoff of coaltion S given that coalition structure κ forms.

(i) $w(N, \{N\}) \geq \sum_{S \in \kappa} w(S, \kappa)$, *and*
(ii) $\forall i \in N, \forall S, T \in \kappa_i(\varnothing)$, $w(i, \kappa_i(\varnothing) \backslash \{S, T\} \cup \{S \cup T\}) \geq w(i, \kappa_i(\varnothing))$.

Condition (1) implies that the grand coalition is the most efficient coalition, while condition (2) implies the existence of positive externalities. Thus, free riders expect to get a higher payoff for non-cooperative behavior than for cooperative one.

The set of free rider games denoted by $\mathcal{FRG}(\mathcal{N})$.

Once can easily see that for every free rider game

$$\min_{\kappa \in \mathcal{P}(N\})} \{w(i, \kappa_i(\varnothing))\} = w(i, [N]), \text{ and} \tag{3}$$

$$\max_{\kappa \in \mathcal{P}(N\}} \{w(i, \kappa_i(\varnothing))\} = w(i, \kappa_{-i}(N)). \tag{4}$$

Hence, a player j is a free rider[6] if and only if $w(j, \kappa_j(\varnothing)) > w(j, [N])$.

For a given partition $\kappa = \{S_1, S_2, ..., S_m\}$ and partition function w, let $\overline{w}(S_1, S_2, ..., S_m)$ denote the m-vector $(w(S_i, \kappa))_{i=1}^m$.

We close this section by introducing a special class of free rider games.

Definition 2.2 *A game* $w \in \mathcal{FRG}(\mathcal{N})$ *is called potential stable if there exists a coalition structure* κ *such that* $w(S, \kappa) \geq \sum_{i \in S} w(i, \kappa_{-i}(S))$ *for every* $S \in \kappa$.

A potential stable game implies the existence of a potentially stable coalition structure in the sense that no player is interested in leaving its coalition to adopt free rider behavior.

3 Feasible allocations

We now pay attention to the final output distributions for free riding problems. First, we introduce some notation and definitions that will be used. Second, we introduce the notion of feasible valuations as reasonable outcomes for a class of free rider games such that a free rider has an incentive to cooperate[7].

[6] **Example 2.2.** Consider the partition function form game w defined by:
$\overline{w}(1, 2, 3) = (0, 0, 0)$, $\overline{w}(12, 3) = (2, 0)$, $\overline{w}(23, 1) = (3, 2)$, $\overline{w}(13, 2) = (2, 1)$, $\overline{w}(123) = 10$. This game has two free riders: player 1 and player 2. Hereby $\min_{\kappa \in \mathcal{P}(N\})} \{w(i, \kappa_i(\varnothing))\} = 0 \; \forall i \in N$, $\max_{\kappa \in \mathcal{P}(N\}} \{w(1, \kappa_1(\varnothing))\} = 2$ and $\max_{\kappa \in \mathcal{P}(N\}} \{w(2, \kappa_2(\varnothing))\} = 1$, whereas $\max_{\kappa \in \mathcal{P}(N\}} \{w(3, \kappa_3(\varnothing))\} = 0$.

[7] We observe that for every game $w \in \Gamma(N)$, a coalition structure κ with $|\kappa| < N$ can be formed if it consists of one of three following kinds of coalitions:
(C1) *A* feasible coalition if $w(S, \kappa) \geq \sum_{i \in S} w(i, [N])$;
(C2) A potentially stable coalition if $w(S, \kappa) \geq \sum_{i \in S} w(i, \kappa_{-i}(S))$;
(C3) A strong stable coalition if S is potentially stable and $w(S, \kappa) = \max_{\kappa_{N \backslash S}} w(S, \kappa_{N \backslash S} \cup S)$.

For every game $w \in \Gamma(N)$ and $i \in N$, the maximum and minimum payoffs that player i can expect to get it in a given game w are defined by

$$\begin{aligned} \theta_i &= \max_{\kappa \in \mathcal{P}(N)} \{w(i, \kappa_i(\varnothing))\}; \\ \eta_i &= \min_{\kappa \in \mathcal{P}(N)} \{w(i, \kappa_i(\varnothing))\}. \end{aligned} \quad (5)$$

The interval $[\eta_i, \theta_i]$ can be considered as a *feasible right* for each player i in the game w.

For every coalition S, we define a *reasonable allocation* (with respect to S in κ) as a vector $x = (x_i)_{i \in S} \in \mathcal{R}^{|S|}$ satisfying $w(S, \kappa) \geq x(S) = \sum_{i \in S} x_i$ and $x_i \geq w(\{i\}, [N])$, for every $i \in S$ (details, for example, see Phamdo (2005)).

Reasonability is simply the requirement that for every coalition, the sum of its allocation values (awards) should not exceed the worth of the coalition, whereas on the other hand the payoffs for player i under reasonable allocation exceed its payoff if the coalition structure consists of singleton coalitions only. The set of all reasonable payoffs for S in w is denoted by $X(S, w)$.

Definition 3.1 *The semi-stable set of w is defined by*

$$SemS(N, w) = \{x \in X(N, w) | \forall S \in \kappa,\ x(S) = w(S, \kappa),\ \textit{and } x_i \geq w(\{i\}, [N]),\ \forall i \in S\}. \quad (6)$$

Semi-stability implies that all players can form a coalition structure such that every player can find a coalition which includes itself such that meeting the demand of all members exactly divides total payoff and the payoff for each $i \in S$ is individually rational[8]. The semi-stable set exists for every free rider game w, as the coalition structure consists of all singletons satisfying all conditions of definition 3.1.

Definition 3.2 *A weighted scheme of coalition S is a collection of real numbers*[9] $\lambda_S = (\lambda_{S,i})_{i \in S} \in R^{|S|}$ *satisfying* $\sum_{i \in S} \lambda_{S,i} = 1$ *and* $\lambda_{S,i} \in [0, 1]$.

[8] Note the difference between the semi-state set and the imputation set known from the characteristic function (TU) game. An imputation is only one vector listing the payoff to each player in the grand coalition, whereas a semi-stable element assigns a vector to every possible coalition (structure), specifying individual payoffs to coalition members and outsiders.

[9] For example, we define an *upper weighted value* is the collection of

$$\lambda_S = (\frac{\theta_i}{\sum_{j \in S} \theta_j})_{i \in S}; \quad (7)$$

and a *lower weighted value* is the collection of

$$\lambda_S = (\frac{\eta_i}{\sum_{j \in S} \eta_j})_{i \in S}, \quad (8)$$

where $\theta_i = \max_{\kappa \in \mathcal{P}(N)} \{w(i, \kappa_i(\varnothing))\}$ and $\eta_i = \min_{\kappa \in \mathcal{P}(N)} \{w(i, \kappa_i(\varnothing))\}$.

Definition 3.3 *A valuation*[10] *is a mapping* Ψ *which associates to each coalition structure* $\kappa \in P(N)$ *a vector of individual payoffs in* R^N.

Definition 3.4 *A weighted valuation is a valuation* Ψ *such that*

$$\Psi_i(S, w) = a_i + \lambda_{S,i} G(S, \kappa), \tag{9}$$

for every coalition $S(i, \kappa)$, *where* $a_i \in [\eta_i, \theta_i]$, $G(S, \kappa) = w(S, \kappa) - \sum_{i \in S} a_i$, *and* $\lambda_S = (\lambda_{S,i})_{i \in S}$ *is a weighted value of* S.

A weighted valuation gives an expected value to each player with respect to the uniform distribution over all the free rider values and the gain from cooperation among players. A weighted valuation is called *proportional valuation* if λ_S is chosen such that $\lambda_{S,i} = \frac{\lambda_i}{\sum_{i \in S} \lambda_i}$, where $\lambda_i \in R^+$.

Following Phamdo (2005), we consider a feasible allocation as a weighted valuation Ψ satisfying the following properties:

(i) *Individual rationality (IR)*: $\Psi_i(w) \geq w(\{i\}, [N])$ for all $i \in N$.
(ii) *Relative efficiency* (*RE*) or feasible value among coalitions:

$$\sum_{i \in S \in \kappa} \Psi_i(S, w) = w(S, \kappa) \text{ for all } w \in \Gamma(N);$$

(iii) *Fair Ranking (FR):* for all players $i, j \in N$ such that if $w(\{i\}, \kappa_{-i}(S)) \geq w(\{j\}, \kappa_{-j}(S))$ implies that $\theta_i \geq \theta_j$ then $\Psi_i(S, w) \geq \Psi_j(S, w)$.
(iv) *Claim right* (*CR*) if for player $i \in N$ such that $\min w(\{i\}, \kappa_i(\varnothing)) = \max w(\{i\}, \kappa_i(\varnothing))$ for all κ then $\Psi_i(S, w) \geq \max w(\{i\}, \kappa_i(\varnothing))$.
(v) *Relative proportion (RP)* if for every player $i \in N$ and $S(\kappa, i)$ if $w(i, \kappa_{-i}(S)) = \lambda_i \sum_{j \in S} w(j, \kappa_{-j}(S))$ then $\Psi_i(S, w) = \lambda_i w(S, \kappa)$ where $\lambda_i \in [0, 1]$ and $\sum_{i \in S} \lambda_i = 1$.

In the rest of this paper we pay attention to proportional valuations where λ_S is an upper weighted value of S. Note that this value splits the surplus or shortage so each gain (if $G(S, \kappa) > 0$) or loss (if $G(S, \kappa) < 0$) in equal proportion to that which could be obtained by each plays as an outsider.

Proposition 3.1 *For every free rider game* $w \in \mathcal{FRG}(\mathcal{N})$, *there exists a proportional allocation 1 satisfying IR, RE, FR and CR.*

Proof. Since $w \in \mathcal{FRG}(\mathcal{N})$, it follows that a coalition S can be formed if $w(S, \kappa) \geq \sum_{i \in S} w(i, [N])$, $\forall S \in \kappa$. We define Ψ by $\Psi_i(S, w) = w(i, [N]) + \lambda_i(w(S, \kappa) - \sum_{i \in S} w(i, [N]))$, where $\lambda_i = \frac{\theta_i}{\sum_{j \in S} \theta_j}$. Then $\Psi_i(S, w) = w(i, [N]) + \lambda_i(w(S, \kappa) - \sum_{i \in S} w(i, [N])) \geq w(i, [N])$, $\Psi(S, w) = \sum_{i \in S} \Psi_i(S, w) = w(S, w)$, the results are straightforward. ∎

[10] The terms " valuation" indicates that each player is able to evaluate directly the payoff s/he obtains in different coalition structures. Valuations thus emerge when the rule of division of the payoffs between coalition members is fixed (for further details, see Bloch, 2003).

Proposition 3.2 *For every potentially stable game $w \in \mathcal{FRG}(\mathcal{N})$, there exists a proportional allocation Ψ satisfying five properties IR, RE, FR, CR and RP.*

Proof. For every $S \in \kappa$, define $\Psi_i(S,w) = w(\{i\},\kappa_{-i}(S)) + \lambda_i G(S,\kappa)$,where $G(S,\kappa) = w(S,\kappa) - \sum_{i\in S} w(\{i\},\kappa_{-i}(S))$, $\lambda_i = \frac{\theta_i}{\sum_{j\in S}\theta_j}$, and $\theta_i = \max_\kappa w(i,\kappa_{-i}(\varnothing))$. Since $G(S,\kappa) \geq 0$, it follows that $\Psi_i(S,w) \geq w(i,[N])$, $\Psi(S,w) = \sum_{i\in S\Psi_i}(S,w) = w(S,\kappa)$. Thus, if $w(\{i\},\kappa_{-i}(S)) \geq w(\{j\},\kappa_{-j}(S))$ implies that $\theta_i \geq \theta_j$ then $\Psi_i(S,w) \geq \Psi_j(S,w)$. Now let $i \in N$ be a player such that $\min w(\{i\},\kappa_i(\varnothing)) = \max w(\{i\},\kappa_i(\varnothing))$. Thus, $\eta_i = \theta_i = w(\{i\},\kappa_i(\varnothing)) \leq w(\{i\},\kappa_{-i}(S)) + \lambda_i G(S,\kappa) = \Psi_i(S,w)$. ■

Example 3.1 *(Phamdo and Norde, 2002) Consider the oligopoly game defined as* $\overline{w}(1,2,3) = (36,16,9)$; $\overline{w}(12,3) = (57.78,18.78)$; $\overline{w}(13,2) = (49,25)$; $\overline{w}(23,1) = (25,49)$ *and* $\overline{w}(123) = 90.25$. *In this game,* $\eta = (\eta_i)_{i=1,2,3} = (36,16,9)$ *and* $\theta = (\theta_i)_{i=1,2,3} = (49,25,18)$. *The proportional rule with upper weighted value* λ_N *leads to* $\Psi(N,w) = (47.66,24.32,18.27)$. *The modified Shapley value would lead to Sh(w) = (46.70,24.71,18.83).*

This example shows that the modified Shapley values assigns more value to players 2 and 3 than player 1, while the proportional valuations assigns more value to player 1 and less value to players 2 and 3.

We define an *adjustment of proportional allocations* $APV(w)$ as

$$APV(w) = \{\Psi(S,w) | \forall S \in \kappa, \forall \kappa \in \mathcal{P}(N) \text{ and } w \in \Gamma(N)\}, \text{ where}$$

$$\Psi_i(S,w) = \begin{cases} w(i,\kappa_{-i}(S)) + \lambda_i G(S,\kappa), & \text{if } S \text{ is potentially stable} \\ w(i,[N]) + \lambda_i(w(S,\kappa) - \sum_{i\in S} w(i,[N])), & \text{otherwise} \end{cases}$$

Proposition 3.3 *Let $w \in \mathcal{FRG}(\mathcal{N})$, then $APV(w) \subset SemS(N,w)$.*

Proof. Let $\lambda_S = (\lambda_i)_{i\in S}$ be a weighted scheme. Since $w \in \mathcal{FRG}(\mathcal{N})$, it follows that $w(S,\kappa) \geq \sum_{i\in S} w(i,[N])$. Therefore,

(i) if S is not a potentially stable, $\Psi_i(S,w) = w(i,[N]) + \lambda_i(w(S,\kappa) - \sum_{i\in S} w(i,[N])) \geq w(i,[N])$

(ii) if S is potentially stable, then $w(S,\kappa) \geq \sum_{i\in S} w(i,\kappa_{-i}(S))$ implies that $G(S,\kappa) \geq 0 \Rightarrow \Psi_i(S,w) = w(i,\kappa_{-i}(S)) + \lambda_i G(S,\kappa) \geq w(i,\kappa_{-i}(S)) \geq w(\{i\},[N])$.

Since $\Psi(S) = \sum_{i\in S} \Psi_i(S,w) = w(S,\kappa) \Rightarrow APV(w) \subset SemiS(N,w)$. ■

The theree propositions above lead to the following Theorem.

Theorem 3.1 *For every free riders game, there exists a feasible allocation that satisfying individual rationality, relative efficiency, fair ranking and claim right. Moreover, if this game is potentially stable then this allocation is relative proportion.*

Remark 3.1 *A game $w \in \mathcal{FRG}(\mathcal{N})$ is potential stable under the grand coalition if* $w(N, \{N\}) = \max_{\kappa \in P(N)} \sum_{S \in \kappa} w(S, \kappa) \geq \sum_{i \in N} w(i, \kappa_{-i}(N))$.

4 Applications

This section presents applications of the feasible allocation to the Baltic Sea codd fishery and the Norwegian spring-spawning herring fishery. The underlying bioeconomic models and calculations are adopted from Kronbal and Lindroos (2005) and Lindroos and Kaitala (2000).

4.1 The Baltic Sea cod fishery

In the Baltic Sea cod fishery there are four participants: four "old" EU member states (Denmark, Finland, Germany and Sweden), four new EU member states (Estonia, Latvia, Lithuania, Poland) and the Russian Federation. The International Baltic Sea Fishery Commission (IBSFC) manages the Baltic Sea cod fishery. The countries participating in the Baltic Sea cod fishery are represented in the IBSFC by their coalitions (1: old EU member states, 2: new EU member states, and 3: European Federation). The optimal strategy of each coalition is to maximize its net present value, given the behavior of the non-members.

There are five possible coalition structures: $[N] = \{1, 2, 3\}$, $\{N\} = \{123\}$, $\{12, 3\}$, $\{13, 2\}$, and $\{23, 1\}$. Table 1 show the payoffs of the coalition structures (Kronbal and Lindroos, 2005).

Table 1. The possible benefits from five coalition structures

Coalition	*Net benefit, Dkr (mil.)*	*Free rider value, Dkr (mil.)*
1	23069	-
2	16738	-
3	15608	-
12	42562	20276
13	41250	21094
23	33544	28456
123	74717	-

Source: Adjusted from Kronbal and Lindroos (2005)

From Table 1, the free riders game w is obtained as follows:

$\overline{w}(1, 2, 3) = (23069, 16738, 15608); \overline{w}(12, 3) = (42562, 20276);$

$\overline{w}(13,2) = (41250, 21094); \overline{w}(1,23) = (28456, 33544); \overline{w}(123) = 74717.$

This game is potentially stable for every coalition structure since $w(S,\kappa) \geq \sum_{i\in S} w(i, \kappa_{-i}(S))$ for all S, and all κ.
Moreover, $w(N, \{N\}) = \max_{\kappa \in \mathcal{P}(\mathcal{N})} \sum_{S\in\kappa} w(S,\kappa) = 74717 \geq \sum_{i\in N} w(i, \kappa_{-i}(N)) = 69826$ implies the stability of the grand coalition[11].

In Table 2 the outcome of proportional allocation rule 2 (Proposition 3.2) is presented. We also present the outcomes of the alternative sharing rules modified Shapley value (Phamdo and Norde, 2002), satisfactory nucleolus (Kronbal and Lindross, 2005) for comparison.[12]

Table 2. The feasible allocations in the Baltic Sea cod fishery

Player	*Free rider share in total value*	*Shapley value*	*Satisfactory nucleolus*	*Proportional allocation 2*
1	28456 (40.8)	29962 (40.1)	30111 (40.3)	30451 (40.8)
2	21094 (30.2)	23013 (30.8)	22714 (30.4)	22571 (30.2)
3	20276 (29.0)	21743 (29.1)	21892 (29.3)	21694 (29.0)

We observe that proportional allocation value is optimal in the sense that each coalition's share is equal to its share under free riding behavior. However, in absolute terms each coalition is better off than under free riding. Another interesting feature of Table 2 is that there are only minor differences between the outcomes of the sharing rules. However, this need not be the case as the following example shows.

4.2 The Norwegian spring-spawning herring fishery

In the Norwegian spring-spawning herring fishery the following nations participate: Norway, Iceland, The Russian Federation, Faeco Islands and some members of the EU. The latter is a distant water fishing nation. Lindroos and Kaitala (2000) argue that on the basis of historical developments the following coalitions are involved in the fishery: coalition 1 (Norway and the Russian Federation), coalition 2 (Iceland and the Faeco Islands) and coalition 3 (EU). Table 3 shows the values of possible coalition structures.

[11] See Pintassilgo (2003) for another implication.

[12] Recall that the modified Shapley value (Phamdo and Norde, 2002) is calculated as the average of the marginal contributions for each player, whereas the satisfactory nucleolus is a modified imputation calculated in a similar fashion as the nucleolus (for details, see Kronbal and Lindroos, 2005). Note that the percentages in brackets are used for convenient comparison.

Table 3. The possible benefits from five coalition structures

Coalition	*Net benefit, Dkr (mil.)*	*Free rider value, Dkr (mil.)*
1	4878	-
2	2313	-
3	896	-
12	19562	14534
13	18141	17544
23	17544	18141
123	44494	-

Source: Lindroos and Kaitala (2000)

From Table 3 the following free riders game w is obtained:
$\overline{w}(1,2,3) = (4878, 2313, 986); \overline{w}(12,3) = (19562, 14534);$
$\overline{w}(13,2) = (18141, 17544); \overline{w}(23,1) = (17544, 18141); \overline{w}(123) = 44494.$

The grand coalition is not stable as $w(N, \{N\}) = 44494 \leq \sum_{i \in N} w(i, \kappa_{-i}(N))$ $= 50219$. Due to the benefits of free riding, Lindroos and Kaitala (2000) conclude that a multilateral agreement is not feasible. However, under the assumption that a coalition (RFMO) can freely merge (accept new members) or break apart (react as singletons) and are farsighted, then the efficient grand coalition can be considered feasible and stable (for further details, see Chander 2003).

The grand coalition can be considered as a case of expanding the RFMO (i.e. new members are allowed to enter RFMO), whereas the non-cooperative situation implies a break up of all members into singleton coalitions[13]. Hence, there are only two alternative coalition structures in the long run under the assumption that all players are farsighted[14] (because the other situations can be considered as intermediate outcomes of the game in the sense that if one of coalition's members wants to deviate, a coalition will split up into singletons). Achieving an agreement, therefore, depends on how each player would evaluate its share from the final surplus.

Since the grand coalition is efficient but not stable, we can resort to two proportional rules (feasible allocations) as two scenarios. For comparison we also present the outcome for the Shapely value. Recall that for every free rider game, the proportional allocation[15] defined in Proposition 3.1 exists (Proportional Allocation 1). However, this allocation is based on the presumption that the share in the total gain (i.e. total surplus $w(N, \{N\})$ is larger than the sum

[13] Observe that under the legal regime of the 1995 UN Agreement the new members appear as a threat to the existing RFMO since the incumbents of the RFMOs do not have the right to bar their access. There are two possible solutions to this problem in the recent literature: "transferable membership" and "waiting period" (for further details, see Munro, 1999). In the first, a system is implemented such that both the prospective members and the incumbents get transferable property rights over the fishery. According to the second, the new member must go through a waiting period before enjoying the benefits from the fishery.

[14] According to Chander (2003), if the players can credibly commit to refrain from coalitions that do not include all players then the grand coalition is stable (Proposition 5).

[15] $\Psi_i = w(i, [N]) + \lambda_i (w(N, \{N\}) - \sum_{j \in N} w(j, [N]))$.

of non-cooperative values $\sum_{i \in N} w(i, [N])$ and does not satisfy the relative proportion property. Therefore, we resort to proportional allocation 2 defined[16] in proposition 3.2.

Table 4 presents the modified Shapley value and the proportional allocation rules for the Norwegian fishery[17].

Table 4. Allocations in the Norwegian fishery.

Player	*Free rider share in total value*	*Shapley value*	*Proportional allocation 1*	*Proportional allocation 2*
1	18141 (36.1)	16030 (36.7)	18030 (40.5)	16074(36.1)
2	17544 (35.0)	14816 (33.3)	15056 (33.8)	15540 (35.0)
3	14534 (28.9)	13348 (30.0)	11418 (25.7)	12880 (28.9)

We observe that the Shapley value provides a better outcome for player 3, and the proportional allocation rule 1 for player 1 whereas the proportional allocation rule 2 is the only rule that preserves the proportional shares under free riding. Note that the Shapley value does not satisfy individual rationality in general, since it is characterized by the expected marginal outcome.

5 Concluding remarks

The purpose of this paper is to analyze the properties of two proportional allocation rules as "fair" sharing rules to a special class of free rider games and shows how these rule can be applied to stimulate cooperation and to discourage free riding. Furthermore, we compare these rules to other sharing devices, notably the modified Shapley value and satisfactory nucleolus. Moreover, two applications to high seas fisheries are presented.

We present five properties that a reasonable and fair sharing rule should meet: individual rationality, relative efficiency, fair ranking, and claim right and show that the proportional allocation rules (feasible rule) have these properties whereas the modified Shapley value and satisfactory nucleolus do not.

We have shown that if all players are free to merge or break apart and are farsighted, then there are enough benefits to make all players better off in the grand coalition (i.e. RFMO) compared to a non-cooperative (break up) or partly cooperative solution (immediate outcomes as waiting period).

Though we have confined ourselves to a particular problem of new members, our analysis can also offer ample scope for future research on the impact of merging or splitting such the cases of Kyoto Protocol with and without USA, Australia, China and India.

[16] $\Psi_i = w(i, \kappa_{-i}(N)) + \lambda_i(w(N, \{N\}) - \sum_{j \in N} w(j, \kappa_{-j}(N))$.

[17] Since the satisfactory nucleolus (Kronbal and Lindroos (2005)) is applicable to a stable game only, we do not use it in this comparison.

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