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Cooperative High-Seas Straddling Stock Agreement as a Characteristic Function Game

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Abstract *In the economic management of high-seas straddling fish stocks, we analyze the negotiation of a cooperative agreement by way of a characteristic function game (c-game). The benefits of a grand coalition may be distributed differently, depending on the negotiating members' harvesting efficiency and the concept of fairness chosen during negotiation. In this paper, we examine three such concepts: nucleolus, Shapley-value, and egalitarian. In general, a fleet's harvesting efficiency will determine the contribution it makes to any subcoalitions, or the grand coalition, in which it is the last to join. Analysis shows that the imputation to each member under each fairness concept differs according to whether the maximum, or the average, contribution is used, or whether the contribution can be regarded as bargaining power at all. By making certain assumptions regarding fleet efficiency, we calculated the exact imputation under each fairness concept and compared the change from one to another. Conclusions are then drawn with suggested further research.*

Key words c-game, high-seas fishery, nucleolus, Shapley-value.

Introduction

A highly migratory fish stock, or the more popular catch-all label of "straddling stock," is a species that can simultaneously occupy a coastal state's 200-mile Exclusive Economic Zone (EEZ) and its adjacent high seas. Although only the relevant coastal state can legally exploit the fishery resource in EEZ waters, the stock is considered to be international common property and is frequently targeted in the high seas by distant water fishing nations (DWFNs). This has arisen as a major issue over the past decade as high-seas fisheries have taken on increasingly significant economic importance. Examples include: (1) the Patagonian toothfish straddling the Antarctic Southern Ocean and Australia's EEZ (Herr 1997); (2) the northern bluefin tuna found from Newfoundland to Brazil in the western Atlantic Ocean, and from Norway to Africa in the eastern Atlantic Ocean (Dean 1997); (3) the immense groundfish fisheries of the Bering Sea over the American EEZ, the Russian EEZ, and a high-seas enclave popularly referred to as the Doughnut Hole (Kaitala and Munro 1993); and (4) the turbot groundfish stock straddling the Canadian EEZ and the high-seas portions of the Grand Bank, which has been the subject of the so-called Canada-Spain turbot war (Munro 1996).

In essence, the New Law of the Sea Convention (United Nations [U.N.] 1992, 1994) granted all states freedom to fish on the high seas and declared that both the

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relevant coastal state and the DWFNs should have a significant management role in the exploitation and conservation of the fishery resource, and in the division of rights and responsibilities among fleets operating in the adjacent high seas.[1] However, the straddling/highly migratory fish stock issue was only recently addressed by a U.N. intergovernmental conference from 1992 to 1995, as high-seas fisheries output escalated.[2] Although the conference brought forth an agreement that calls for the concerned resources to be managed through regional fisheries management organizations, it did not provide an answer as to what is required to turn these organizations into genuinely effective resource management bodies. Kaitala and Munro (1993) attempted to answer this by proposing that the organizations will have to become closed; if not in law, then in the sense that the original members of an organization, including some DWFNs, will have to become *de facto* collective property owners of the resource, or resources. Implicit in the proposal is the assumption that the straddling fish stock is already fully utilized in terms of both profitability and sustainability. Thus, the incumbent fleets should become the sole beneficiaries of the fishery resource, but must also observe related international conventions on resource sustainability and environmental protection (U.N. 1994; OECD 1997).[3] Hence, a potential new entrant can only access the fish stock in question by buying out the fishing rights and quota of an incumbent fleet or nation (Kaitala and Munro 1995). However, it is not immediately evident that such an assumption on economic efficiency and resource sustainability is valid.

In this paper, we suggest that the Kaitala-Munro prescription may not be necessary. Instead, we consider the entire high-seas straddling stock as a common property and that all willing participants are allowed to access it.[4] However, these participants (fleets or nations) must agree to a legally binding cooperative arrangement through an international convention under which harvesting of the stock must be sustainable and economically efficient. The distribution of benefits resulting from the grand coalition is to be determined equitably by a consensual bargaining process.[5] Essentially, this means adopting a commonly agreed concept of fairness which, in turn, will specify how the distribution scheme will work in a consensus. Naturally, for political or economic reasons, the number of willing participants to the straddling stock will change over time so that the harvesting (total catch and its distribution over both time and sectors within one season), concept of fairness, and fishery rent bargaining will be renegotiated. However, the renegotiated outcome must be cooperative, legally binding, and strictly adhered to for as long as the num-

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[1] It has been argued that the "consistency principle" should be adopted in which the management regime applied to the portion of the stock in the adjacent high seas must be consistent with the management regime established by the coastal state for the portion of the stock within the EEZ. However, the coastal state alone determines the latter management regime and, *ipso facto,* it will also likely dominate the former. As expected, the principle was criticized as "creeping jurisdictionalism," and, instead, a cooperative management regime was called for to be administered through an international organization (Kaitala and Munro 1993, p. 318).

[2] Catch by DWFNs reached 8 million metric tons (MMT) out of the world's total commercial marine catches of 80 MMT in the early 1990s, up from only 1 MMT out of a world total of 30 MMT in the 1960s (OECD 1997, pp. 29–30).

[3] "Fleets" and "nations" can be used interchangeably in this paper.

[4] Strictly speaking, only the high-seas portion of the straddling stock can be considered common property. In reality, it may be impossible, if not at considerable cost, to quantify this portion. At any rate, applying the entire stock to a cooperative agreement does not jeopardize its efficient and sustainable harvesting. Naturally, the share of fishery resource rent under the agreement to any member nation will be different from that to the same nation if it had partial jurisdiction over the stock through an existing EEZ. However, it will be shown that the fleet efficiency developed over proximity to this fish stock by the coastal nation will enhance its bargaining power and its share of the benefits in the grand coalition.

[5] The benefits of a grand coalition include only the additional fishery rent over and above the sum total of all participants' threat-point fishery rents, calculated under a noncooperative feedback Nash equilibrium (Clark 1990).

ber of participants remains constant and the agreement remains ratified. Arguably, the common property assumption will attract nations that are wholly inefficient in harvesting the straddling stock, and that will be in the agreement simply to free-ride on the benefits of the grand coalition. However, as we will show in the analysis, a suitable concept of fairness will guarantee that a participant's share of the benefits will depend on its contribution to the grand coalition. Since inefficient fleets contribute little, they receive little.

In solving for such a cooperative outcome, the solution will also address two central problems of the economic management of high-seas straddling fish stock: (1) more participants involved than simply one coastal state and one distant water fishing nation;[6] and (2) potential new entrants to the fishery. To demonstrate how such a cooperative agreement can be analyzed as a characteristic function game (c-game), we identify the willing participants as one coastal EEZ and one DWFN that are both incumbents to a straddling stock, and a second DWFN as a potential new entrant to the fishery (Mesterton-Gibbons 1992). We will show that both the incumbents and the potential entrant can all gain from joining the grand coalition, thereby providing incentives for cooperation.

Recognizing the stock as commonly owned, all three participants then negotiate and bargain for a cooperative agreement. Once successfully implemented, the agreement will become legally binding in all its obligations regarding efficient harvesting, sustainability, the environment, and the division of harvest shares. In addition, a mutually accepted system for internal transfer payments and a mutually agreed upon concept of fairness on which the distribution of fishery rent from the grand coalition to each individual member is based, will be reached.

In the following sections, the cooperative grand coalition as a c-game is set up. Next, the concepts of fairness are explained, and the means by which they affect the allocation of cooperative benefits is subsequently made clear. The various allocation schemes are then discussed, followed by a summarization of the results and suggestions for further research.

A Characteristic Function Game

To begin, the coastal nation, the incumbent DWFN, and the potential DWFN entrant are labeled as 1, 2, and 3, respectively. Next, a few assumptions regarding the negotiating nations are listed. First, suppose that the three nations are the only willing participants in the harvesting of the straddling stock. All other potential harvesting nations voluntarily abstain from the stock because of either prohibitively high harvesting costs, low fleet efficiency, or sheer distance from the fish stock. Second, there exists complete information regarding the negotiating members' fleet efficiency.[7] This is the basis on which each fleet's contribution in terms of fishery rent to the grand coalition is calculated. The importance of this with regards to the choice of an acceptable concept of fairness in distributing the coalition benefits, and

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[6] This problem is conceptually identical to the "shared" or transboundary fish stock management problem between two adjoining coastal EEZs and thus can be solved accordingly (Clark 1990). Armstrong (1994) also applies the cooperative and cooperative-compensated solutions to the problem involving two participants—the Russian-Norwegian comanagement of the Arcto-Norwegian cod stock.

[7] This assumption also deters wholly inefficient fleets outside the negotiating nations from free-riding on the imminent grand coalition, since they contribute little to it and everyone knows it. There is, of course, nothing preventing them from harvesting outside the grand coalition, but they will soon be driven out of the fishery once the more efficient grand coalition is in place. If these fleets had been efficient enough to compete with the grand coalition, they would have chosen to be a negotiating member and part of a potentially successful grand coalition. Analysis shows they would earn more that way.

thus the success of the negotiation, will become clear as the analysis proceeds. Third, they face the same competitive market price for their harvest outputs, but with increasing harvest (fishing effort) costs in the order of 1 < 2 < 3. This assumption can be maintained by sufficiently restricting capital mobility between nations. Lastly, assume that the optimal stock levels, y_i^*, and bionomic equilibrium levels, y_i^∞, i = 1, 2, 3, of each fishing nation, if the nations harvest noncooperatively, are in the following order:[8]

$$y_3^* > y_2^* > y_1^* > y_3^\infty > y_2^\infty > y_1^\infty \tag{1}$$

Therefore, without cooperation, the conservationists (2 and 3) will be driven out of the fishery after harvesting becomes nonprofitable for them in a certain period of time. This happens once the most efficient nation, 1, has depleted the straddling stock sustainably to 2's bionomic equilibrium, y_2^∞. When this occurs, a Nash feedback equilibrium is said to be established. Assuming that all other nations in the fishery follow their optimal harvesting strategies, no single nation can do better by deviating from theirs.[9] We define the total returns to each nation as J_i, i = 1, 2, 3, depending on the initial straddling stock size. The J_i's are known as the threat-point fishery returns to the participants of a cooperative stock agreement. By definition, the cooperative agreement must offer each member additional fishery return (through bargaining) strictly over and above their threat points as an incentive to join the grand coalition.

Suppose the grand cooperative stock agreement is not yet negotiated. If two fishing nations form a subcoalition among themselves and harvest cooperatively against the remaining fishing nation, they stand to earn a combined fishery return that is larger than their threat-point sum total. For example, if 1 and 2 form a harvesting subcoalition, the additional fishery return over and above their sum total is:

$$e_{12} = w_{12}^1 - (J_1 + J_2) \tag{2}$$

where w_{12}^1 is the combined fishery return to 1 and 2 if they harvest cooperatively. A likely candidate for such cooperative harvesting is the following: the less efficient 2 allows 1 to dictate the harvesting policy for the subcoalition as well as dominate fishing effort and total allowable catch (TAC). Nation 2 will likely be required to cease fishing altogether, while 1 depletes the straddling stock to y_3^∞ and eventually drives their competitor, 3, out of the fishery. Clearly, this will lead to less uneconomical overexploitation of the stock than the Nash feedback equilibrium. Therefore, e_{12} must be strictly positive. However, in allowing 1 to do so, 2 needs to be compensated with a fair share of e_{12}.

Along a similar vein, the additional combined fishery return to 1 and 3, if they harvest cooperatively by forming a subcoalition, is:

$$e_{13} = w_{13}^1 - (J_1 + J_3) > 0 \tag{3}$$

where 1 is allowed to dictate over 3, who will be compensated accordingly. For 2 and 3, the additional combined fishery return is:

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[8] Given an initial stock size, the optimal stock level maximizes the resource rent through a most rapid approach path (MRAP) for the harvesting effort, whilst the bionomic equilibrium fully dissipates the resource rent, or equivalently, discounts the fishery's future productivity completely through an infinite social discount rate (Clark 1990).

[9] This is equivalent to the noncooperative feedback solution to an unregulated open-access, or common-capture, fishery resource. The same would result if unlimited access was allowed to the straddling stock by multiple new entrants, in which no amount of negotiation could lead to a successful cooperative agreement (Clark 1990).

$$e_{23} = w_{23}^{2} - (J_2 + J_3) > 0 \tag{4}$$

where 3 surrenders to 2 until both are driven out of the fishery by 1. Finally, the additional combined fishery return to the grand harvesting coalition involving 1, 2, and 3 is:

$$e_{123} = w_{123}^{1} - (J_1 + J_2 + J_3) > 0 \tag{5}$$

where 2 and 3 will cease fishing altogether while 1 depletes to y_1^* sustainably at the very outset of the cooperative agreement, once successfully negotiated.

In each case, the more efficient member of the subcoalition or grand coalition is allowed to dictate the overall harvesting policy. This almost always requires the less efficient nations to stop fishing and forces them to rely on bargaining for their share of benefits. These are then most efficiently executed through an internal transfer payment process.[10,11]

Because of the assumed order of harvesting costs and threat-point fishery returns among 1, 2, and 3 in equation (1), it is reasonable to postulate that the additional returns to various subcoalition and grand coalition combinations satisfy the following:

$$e_{123} > e_{12} > e_{13} > e_{23} > 0 \tag{6}$$

In other words, the scope for noncooperative, uneconomical overexploitation of the straddling stock also increases in the same order. Equation (6) also explains why the incumbents (1 and 2) would voluntarily allow the new entrant, 3, to join the club and negotiate for a grand coalition in the first place:

$$e_{123} - e_{12} = (w_{123}^{1} - w_{12}^{1}) - J_3 > 0 \tag{7}$$

This additional gain, $(w_{123}^{1} - w_{12}^{1}) - J_3$, will be bargained over and shared among the members during the negotiation for the agreement. The existence of such gain comes from preventing the initial uneconomical overexploitation, which would have resulted-had the incumbents competed against the new entrant. This is because the new entrant cannot be prevented, by international law, from operating in the high seas. Although the less efficient new entrant would eventually be driven out of the fishery, such open-access destructive competition would seriously dissipate the fishery rent.

For every harvesting subcoalition, we can define the characteristic function as:

$$v(s) = e_s/e_{123} \tag{8}$$

where s is any subcoalition (or the grand coalition), including single members, from the set of {1, 2, 3, 12, 13, 23, 123}. In other words, $v(s)$ is the benefit generated by

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[10] By allowing the most efficient nation to dominate over fishing effort and the TAC, internal payments will make the most efficient output (and maximum possible profit for the agreement as a whole) feasible from its previously infeasible position (before internal payments), where the threat-point return to at least one member was threatened. Furthermore, internal payments produce linearly distributed profits for the agreement as a whole, strictly over and above the concave Pareto-efficient frontier for competing harvests (Kaitala and Munro 1993). See also Armstrong (1994) for a discussion of the payment negotiation framework and the stages of decision making.

[11] As Kaitala and Munro point out (1995, p. 308), we could make one of the DWFNs the most efficient and, hence, the dominant fishing nation in the agreement. Then the coastal nation, with its adjoining EEZ under an unconstrained harvest share assumption, will have to cease fishing altogether and rely on bargaining for its share of the total economic rent. This may not be politically palatable.

the harvesting subcoalition, *s*, expressed as a proportion of the benefits generated in the grand harvesting coalition. Clearly, single member subcoalitions contribute nothing to the alleviation of noncooperative, uneconomical overexploitation, so that $v(1) = v(2) = v(3) = 0$. We further define the vector $\mathbf{x} = (x_1, x_2, x_3)$ as the imputation (allocation) that completely describes the way the benefits of the grand coalition are distributed among the cooperative members. Naturally, **x** is the negotiated outcome of a international bargaining process peculiar to a cooperative straddling stock agreement with a certain chosen concept of fairness. Finally, a successful grand coalition imputation **x** must necessarily satisfy two further requirements:

$$x_i > 0,\ i = 1, 2, 3 \text{ (individual rationality)} \tag{9}$$

and

$$\Sigma x_i = 1 \text{ (group rationality or Pareto-optimality).} \tag{10}$$

The Nucleolus

As a concept of fair distribution, the nucleolus is essentially a maxi-min imputation into the members of a successfully negotiated cooperative agreement. The combined benefits over and above the sum total of all members' threat-point returns are shared in a manner that the minimum gain to any one member is maximized. It requires the computation of each member's excess and the least rational core of such excesses. If the least rational core reduces to a single point, then the nucleolus is found. If not, there are other solution concepts. To illustrate this particular concept of fairness, certain assumptions are made regarding the fleets' efficiency to ensure the nucleolus in this problem exists and is unique.

Suppose the nucleolus is found and the subsequent imputation is **x**, then the excess of any subcoalition over the sum total of its members' imputed share of the grand coalition benefits is defined as:

$$ex(s) \leq \varepsilon \tag{11}$$

where $s \in \{1, 2, 3, 12, 13, 23, 123\}$, and

$$ex(s) = v(s) - \Sigma_{i \in s}\, x_i \tag{12}$$

The right-hand side of the inequality [equation (11)] should be negative for all subcoalitions. Otherwise, members of subcoalitions where this is not the case would have done better by staying put with their more profitable subcoalitions and not have accepted the imputation **x** during the negotiation for the cooperative agreement in the first place. By restricting all excesses to be at most ε, we can find the least ε such that the smallest share (in the grand coalition) to members of any potential subcoalitions will be maximized. By working out all possible subcoalitions (including single members) we find that:

$$ex(i) = -x_i \leq \varepsilon;\ i = 1, 2, \text{ or } 3 \tag{13}$$

$$ex(12) = e_{12}/e_{123} - x_1 - x_2 \leq \varepsilon \tag{14}$$

$$ex(13) = e_{13}/e_{123} - x_1 - x_3 \leq \varepsilon \tag{15}$$

$$ex(23) = e_{23}/e_{123} - x_2 - x_3 \leq \varepsilon \quad (16)$$

Using the Pareto-optimality condition (equation [10]), we obtain the following inequalities in which the least excess, ε, and the nucleolus (if it exists) are embedded:

$$-\varepsilon \leq x_1 \leq \varepsilon + 1 - e_{23}/e_{123} \quad (17)$$

$$-\varepsilon \leq x_2 \leq \varepsilon + 1 - e_{13}/e_{123} \quad (18)$$

$$-\varepsilon \leq x_3 \leq \varepsilon + 1 - e_{12}/e_{123} \quad (19)$$

$$e_{12}/e_{123} - \varepsilon \leq x_1 + x_2 \leq 1 + \varepsilon \quad (20)$$

The following can be derived solely from inequality (19):

$$\varepsilon \geq -1/2 + 1/2\ e_{12}/e_{123} \quad (21)$$

while the following two are derived from inequalities (17), (18), (19), and (10):

$$\varepsilon \geq -1/3 \quad (22)$$

and

$$\varepsilon \geq -2/3 + 1/3\ (e_{12} + e_{13} + e_{23})/e_{123} \quad (23)$$

To find the least ε, inequalities (21), (22), and (23) must be satisfied simultaneously. However, an initial guess for the least ε is sufficient if it can lead to the best that the nucleolus imputation $\mathbf{x} = (x_1, x_2, x_3)$ can achieve—in the least rational core embedded in inequalities (17) to (19). Suppose we guess that the least ε, *i.e.*, the simultaneous solution for inequalities (21), (22), and (23), is the right-hand side of inequality (23), then the inequality in (21) is true provided that

$$-1/2 + 1/2\ e_{12}/e_{123} \leq -2/3 + 1/3\ (e_{12} + e_{13} + e_{23})/e_{123}$$

or

$$1 + 3\ e_{12}/e_{123} \leq 2\ (e_{12} + e_{13} + e_{23})/e_{123} \quad (24)$$

At the same time, inequality (22) is also true provided

$$-1/3 \leq -2/3 + 1/3\ (e_{12} + e_{13} + e_{23})/e_{123}$$

or

$$1 \leq (e_{12} + e_{13} + e_{23})/e_{123} \quad (25)$$

In other words, inequalities (24) and (25) are sufficient assumptions for the right-hand side of inequality (23) to be the least ε. As a result, the right-hand sides of inequalities (17), (18), and (19) are the only nucleolus imputations that satisfy the Pareto-optimality requirement in equation (10):

$$x_1(\text{nucleolus}) = 1/3 + (e_{12} + e_{13} - 2e_{23})/3e_{123} \quad (26)$$

$$x_2(\text{nucleolus}) = 1/3 + (e_{12} + e_{23} - 2e_{13})/3e_{123} \quad (27)$$

$$x_3(\text{nucleolus}) = 1/3 + (e_{13} + e_{23} - 2e_{12})/3e_{123} \quad (28)$$

Furthermore, substituting the least ε in assumption (24) gives:

$$\varepsilon \geq -2/3 + 1/6\ (1 + 3\ e_{12}/e_{123}) = -1/2 + 1/2\ e_{12}/e_{123}$$

Then, inequality (19) and assumption (6) will guarantee that individual rationality condition (9) is also satisfied:

$$x_1 \geq x_2 \geq x_3 \geq -\ (-1/2 + 1/2\ e_{12}/e_{123})$$
$$= \frac{1}{2}(1 - e_{12}/e_{123}) \geq 0$$

Taking the excess, as that of the right-hand side of inequality (23), will ensure that the smallest gain to any one participant (by themselves or as members of subcoalitions) by cooperating in the grand coalition is maximized. This makes the resulting distribution scheme somewhat fair in their eyes. Of course, this fairness is predicated on the more efficient fleets getting a larger share because of their disproportionately larger contributions to the grand coalition. In this concept, fairness does not mean giving disproportionately more to the less contributory participants.

The Shapley-value and Egalitarian Imputations

The preceding analysis was predicated on the assumption that all fishing nations are free to form subcoalitions, or the grand coalition, with whomever they like. Any existing subcoalitions, or the grand coalition, can be broken down without hampering the remaining or exiting members from forming new subcoalitions. This gives the efficient fleets more negotiating power, as they can bargain for a larger share of the grand coalition benefits based on their maximum contributions to any subcoalitions, or the grand coalition, in which they are the last joining members. To counter such bargaining power, the less efficient fleets can argue that the share to any one participant of the grand coalition should be based on its average, not maximum, contribution. This is the concept of fairness based on Shapley-values.

The concept of Shapley-value can be understood via the *reasonable set*, which defines the share to any member, x_i, as

$$x_i \leq \max_s \{v(s) - v(s - i)\},\ i = 1, 2, \text{ or } 3;\ s \in \{1, 2, 3, 12, 13, 23, 123\} \quad (29)$$

where x_i also must satisfy conditions (9) and (10). In other words, the reasonable set for any fishing nation, *i*, is based on the marginal fishery benefits contributed to any harvesting subcoalitions, or the grand harvesting coalition, by nation *i*, which is the last to join. For example, by forming a subcoalition with 2, 1 contributes e_{12} to subcoalition s = 12; by forming the grand coalition 123 with 2 and 3, 1 contributes $e_{123} - e_{23}$ to the grand harvesting coalition; and so on. Therefore, the reasonable set for member *i* requires that the share of fishery benefits to *i* from the grand coalition be, at most, the maximum marginal contribution that *i* makes to any subcoalitions or the grand coalition. It can be shown that if the reasonable sets for all members in the grand coalition consist of a single imputation **x**, then this imputation is the nucleolus (Mesterton-Gibbons 1992). On the other hand, the less contributory members may argue that a fairer share of fishery benefits from the grand coalition to any member *i* should be the average (expected), not maximum, marginal contribution of that member to any subcoalitions or the grand coalition. In other words,

$$x_i(\text{Shapley}) = E_s[v(s) - v(s - i)],\ i = 1, 2, \text{ or } 3 \tag{30}$$

where $s \in \{1, 2, 3, 12, 13, 23, 123\}$

To calculate the expectation, we must know how often fishing nation *i* contributes what, to which subcoalition, or the grand coalition. First, we enumerate all possible sequences for every fishing nation to join the grand coalition. They are:

$$\{123, 213, 231, 132, 312, 321\} \tag{31}$$

For x_1(Shapley), 1 does not contribute anything (in terms of alleviating the noncooperative uneconomical overexploitation) if it is the first to appear in the grand coalition. This happens with a probability of 2/6 = 1/3 [the first and fourth terms in set (31)]. When 1 is the second to join the grand coalition, it contributes $v(12)$ to the subcoalition $s = 12$ with probability 1/6 if 2 is the first to join, and contributes $v(13)$ to the subcoalition $s = 13$ with probability 1/6 if 3 is the first to join. When 1 is the last to join the grand coalition, it contributes $v(123) - v(23)$ to the grand coalition $s = 123$ with probability 2/6 = 1/3. Therefore,

$$\begin{aligned} x_1(\text{Shapley}) &= 0 \cdot 1/3 + (e_{12}/e_{123} + e_{13}/e_{123}) \cdot 1/6 + (1 - e_{23}/e_{123}) \cdot 1/3 \\ &= 1/3 + (e_{12} + e_{13} - 2e_{23})/6e_{123} \end{aligned} \tag{32}$$

Similarly,

$$x_2(\text{Shapley}) = 1/3 + (e_{12} + e_{23} - 2e_{13})/6e_{123} \tag{33}$$

$$x_3(\text{Shapley}) = 1/3 + (e_{13} + e_{23} - 2e_{12})/6e_{123} \tag{34}$$

The imputation of the grand coalition benefits based on the participants' Shapley-values, as captured in equations (32) to (34), are displayed in table 1 alongside the nucleolus imputation.

There is also a third type of imputation in which the benefits of the grand coalition are to be distributed equally, *i.e.*

$$x_i(\text{egalitarian}) = 1/3,\ i = 1, 2, \text{ or } 3 \tag{35}$$

Such an imputation, if it actually occurs, implies that every member of the grand coalition has equal bargaining power. Therefore, if any one member were to withdraw, the grand coalition would collapse. Further subcoalitions between any withdrawing or remaining participants would be prohibited, and everyone would earn back only their threat-points. Equation (35) is also displayed in table 1 for comparison with the other two types of imputation. The quantitative comparisons (inequalities) contained in table 1 can be easily verified using assumption (6).

Table 1
Exact Solutions for the Nucleolus, Shapley-Value, and Egaliatarian Imputations

x_i	Nucleolus Imputation		Shapley-Value Imputation		Egalitarian Imputation
x_1	$1/3 + (e_{12} + e_{13} - 2e_{23})/3e_{123}$	≥	$1/3 + (e_{12} + e_{13} - 2e_{23})/6e_{123}$	≥	1/3
x_2	$1/3 + (e_{12} + e_{23} - 2e_{13})/3e_{123}$	≥ or ≤	$1/3 + (e_{12} + e_{23} - 2e_{13})/6e_{123}$	≥ or ≤	1/3
x_3	$1/3 + (e_{13} + e_{23} - 2e_{12})/3e_{123}$	≤	$1/3 + (e_{13} + e_{23} - 2e_{12})/6e_{123}$	≤	1/3
Σx_i	1		1		1

Comparing Various Imputation Schemes

The results from table 1 clearly show that the share of total benefits, in terms of the additional fishery rents, over and above the sum total of each participant's threat-point in the grand coalition, is increasing with the participant's fleet efficiency. However, such an advantage drops steadily from the nucleolus imputation to the Shapley-value imputation to the egalitarian imputation.

The rationale for the efficiency advantage is that efficient fleets contribute incrementally more to any subcoalitions, or the grand coalition, involving them as the last joining members. If the grand coalition is unsuccessful, these fleets could still form subcoalitions or harvest on their own. Thus, the grand coalition involving these fleets must give them a larger share as an incentive for them to join.

The reason that the efficiency advantage of these fleets drops in the above order, is because the nucleolus imputation is based on the maximum contribution (hence, maximum bargaining power) that each participant can potentially make. On the other hand, the Shapley-value imputation is based on the average marginal contribution that each participant can potentially make. The egalitarian imputation, of course, disregards all participants' fleet efficiency and gives equal bargaining power to each. Thus, the nucleolus imputation is greater than the Shapley-value imputation, and that is greater than the egalitarian imputation.

Conclusions and Further Research

In this paper, the problem of an acceptable benefits-sharing scheme in a cooperative high-seas straddling fish stock agreement has been examined. A starting point is that the incumbents to a high-seas fishery stock may not be harvesting efficiently and sustainably. Incentives then exist for all willing participants (both incumbents and potential new entrants) of this commonly owned fishery to form a cooperative grand coalition in sustainable harvesting and earn more than their noncooperative, unsustainable, uneconomical, and inefficient common-access threat-point returns. The problem is then reduced to one of sharing the benefits due to cooperation in a fair manner, such that the negotiation process will eventually lead to a benign environment for the grand coalition. If the negotiation is successful and monitoring is effective, the grand coalition will typically nominate the most efficient fleet to be the all-powerful coalition manager. It will dictate an efficient and sustainable total allowable catch (TAC) with unconstrained harvest share to itself and/or other comparatively efficient fleets. Then, the resulting fishery rent that is extracted, over and above the total of every participant's threat-point, will be shared through an internal transfer payment system. If at any time the grand coalition changes in size, the above process will be repeated, presumably with renegotiation of the distribution scheme and the concept of fairness.

The problem of sharing fairly is now crystallized from the cooperative agreement. Not only is it necessary to prevent wholly inefficient fleets from staking a claim on the straddling stock, it is also vital to a successful negotiation and a grand coalition. Suppose that, should the negotiation be unsuccessful and the grand coalition not form, no hindrance exists to any of the fishing nations forming subcoalitions in pursuit of profitable harvesting. Then, in general, the more efficient fleets will be able to negotiate for a larger share of the benefits of cooperation in the grand coalition, either through these fleets' own harvesting efficiency, or through the disproportionately large benefits that their subcoalition would contribute to the grand coalition. Moreover, their ability to get a larger share of the benefits of cooperation will also be judged fair by the less efficient fleets, thereby paving the way to a successful cooperative agreement. After all, should the grand coalition fail, the less efficient fleets can only retain their low threat points or marginally improve on their threat points, even if they form a subcoalition among themselves.

Of course, how fair the sharing should be before the grand coalition is successful depends entirely on the participants' choice. There are at least three concepts of fairness for the participants to choose from: (*i*) maximizing the minimum gains (of cooperating in a grand coalition) to any one participant (nucleolus); (*ii*) calculating the share to any one participant by the average contribution that it makes to any subcoalitions, or the grand coalition, involving that participant as the last entrant (Shapley-value); or (*iii*) simply giving everyone the same share (egalitarian). It is difficult to predict whether the egalitarian distribution will definitely ensure a successful cooperative agreement as the more efficient fleets may not acquiesce.

In our analysis, the following assumptions were made to illustrate how the distribution of the cooperative benefits could be calculated exactly: (1) willing participants are free to form subcoalitions in the event of collapse of the grand coalition; (2) benefits to cooperation will increase with the number of participants; and (3) efficient fleets contribute more benefits to any subcoalitions, or the grand coalition, involving them as the last joining members. Assumptions (1) and (2) will guarantee an exact Shapley-value imputation, while (3) further allows a unique imputation solution in the nucleolus distribution. Not surprisingly, the resulting share for the less efficient fleets increases from the nucleolus distribution, to the Shapley distribution, to the egalitarian distribution, but vice versa for the more efficient fleets.

Further research on this topic must include canvassing other concepts of fairness and how they will affect the sharing scheme in both the direction and magnitude of distribution. In addition, an understanding of the nucleolus distribution of fishery benefits in the grand coalition can also be enhanced by examining multiple imputation solutions or none at all. In either case, the concept of nucleolus fairness will have to be refined through other means.

Relaxing the complete information assumption should lead to more realistic, but complicated, analysis. Not only will wholly inefficient, free-riding, and potential new entrants be difficult to sift out, but the incumbents must also subjectively assess the gains, and, therefore, the bargaining power, from forming various subcoalitions or the grand coalition. Presumably, their private assessments would be influenced by the signals sent out from other incumbents or new entrants when they form subcoalitions. These subcoalitions must also determine whether sending out such signals is perceived by their intended recipients to be a credible strategy.

Finally, increasing the number of negotiating members (from 2 incumbents and 1 new entrant) might complicate the analysis, but should not introduce conceptual difficulties. It is expected that total efficiency gains from a grand coalition will increase with the number of participants, but the universal acceptance of a concept of fairness for benefits distribution will also become increasingly difficult. The problem of free-riding will become more severe. In the end, full utilization of the stock might have to be declared, effectively forever barring new entrants, including truly efficient ones.

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