SHARING THE BENEFITS OF COOPERATION IN A HIGH SEAS FISHERY GAME: AN APPLICATION OF THE NUCLEOLUS

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Abstract. In the current paper, we examine a game-theoretic setting in which three countries have established a regional organisation for the conservation and management of straddling and highly migratory fish stocks. A characteristic function game approach is applied to describe the sharing of the surplus benefits from cooperation. We demonstrate that the nucleolus and the Shapley value give more of the benefits to the coalition with substantial bargaining power than does the Nash bargaining scheme. We also compare the results that are obtained by using the nucleolus and the Shapley value as solution concepts. The outcomes from these solution concepts depend on the relative efficiency of the most efficient coalition. Furthermore, the question of fair sharing of the benefits is considered in the context of straddling stocks.

Keywords: High seas fisheries, straddling and highly migratory stocks, nucleolus, characteristic function games, coalitional bargaining, fair imputations, Shapley value

1 INTRODUCTION

The common objective of International Environmental Agreements (IEAs) is to solve disputes concerning the economic, social and political aspects of natural resource use and environmental protection. The marine resources including fish stocks, which are the main issue of this paper, have traditionally been treated as common property, or more precisely, open-access resources. During this present century, however, fishing

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gear and methods have developed so rapidly that many of the valuable fish stocks have collapsed. As the fishery resources have become scarcer, the more severe the disputes over its use have been. In the 1950's, it was commonly believed that marine resources were perpetual (Gordon 1954) i.e. more fishing effort would yield a larger catch. As this assumption proved to be false, a new kind of property rights regime had to be implemented.

In 1982, the Law of the Sea Convention (UN 1982) was ready for signature and ratification in the United Nations. The main purpose of the agreement was to establish a 200 mile Exclusive Economic Zone (EEZ), where each coastal state would have sovereign rights over the marine resources within this zone. The high seas, where no nation has jurisdiction of its own, constituted a smaller part of the world's oceans after the agreement. It was generally assumed that this agreement would define the property rights of the fishing nations so well that there would be no more fishing disputes. This seemed to be a logical assumption, since 90% of the world's fish is estimated to be found within EEZs.

Nevertheless, the fishing disputes are still here, and they even have become more severe. They are quite often called fish wars, and this term is not very far from reality because the presence of military vessels is sometimes used to ensure the safe passage of fishers on the high seas. Many of the recent fishery disputes have concerned the harvesting of straddling and highly migratory fish. Both these stocks cross the boundaries of the exclusive economic zones of coastal states (EEZ), thus occurring also in the adjacent high seas areas, and are currently the subject of many international fisheries disputes. The problems of high seas fisheries were also noted at the Rio environmental conference in 1992. The process of resolving related international conflicts culminated in the signing of the United Nations Convention in December 1995 (United Nations 1995). The Convention suggests cooperation through regional fishing organisations and arrangements, where all countries interested in fishing in the region are allowed to participate.
It has been argued in the fisheries economics literature that the well-developed theory of shared fish stock resources is insufficient to meet the demands of the economic analysis of the new Convention (Kaitala and Munro 1995). This is due to the fact that in the case of shared fish stocks there are only a few, and a fixed number of, nations involved. In the case of straddling fish stocks the number of potential participants (players) is not fixed but may grow in the unknown future - the fisheries organisations managing straddling fish stocks and highly migratory fish stocks are now open, at least in principle, to new member states. In this paper, we attempt to gain further insight into the analytical and economic problems faced by the nations involved in the negotiations on the management of straddling stocks. In particular, we study here the game-theoretic setting characterised by characteristic functions (c-games).

The conventional Nash bargaining approach (1953) that has been widely used in fisheries economics studies assumes that the bargaining power of the fishing nations arises from their potential losses or gains from cooperation as compared to non-cooperation. The c-game approach (Mesterton-Gibbons 1992) assumes a rather different perspective: the fishing nations have no bargaining power on their own. It is the coalitions that the countries can form with one another that define their contribution in the cooperative agreement and consequently their bargaining strengths. The c-game approach is an appropriate alternative for analysing new environmental agreements and cooperative organisations.

The economics of straddling stocks have been analysed earlier by Kaitala and Munro (1995, 1996, 1997), Kaitala and Lindroos (1997a, 1997b) and Naito and Polasky (1997). The c-games approach has been used in transboundary pollution models by, for example, Chander and Tulkens (1994). See Tulkens (1997) for a discussion about the various coalitional approaches to international pollution problems. In addition, Filar and Gaertner (1996) have applied the Shapley value to global pollution problems. In the current paper, we consider a fisheries organisation of three member states. We assume that a consensus is reached during the negotiations on the cooperative management of straddling and highly migratory fish stocks through a regional fisheries management organisation, as suggested in the United Nations Convention.
Our results provide a starting point for a better chance to resolve the new member issue. Since there may be no restrictions for new fishing states to enter the organisation and enjoy the benefits, the equal sharing rule that the Nash bargaining scheme proposes might be inadequate to meet the needs of the situation concerning the straddling stocks, as already demonstrated by Kaitala and Munro (1997).

The current paper, in Section 2, first defines the most important concepts in the analysis of high seas fisheries and reviews some of the results already achieved in the theory of transboundary fishery resources. Section 3 then defines the structure of the game in coalitional or characteristic function form. We assume that there is only one two-player coalition that has bargaining power during the negotiations, and its value determines the sharing of total benefits from cooperation for all three players, at least at the beginning of the game. In Sections 4 and 5, the issue of the fair solution is examined by the means of the nucleolus, and the results are compared with the results previously obtained by using the Shapley value. In addition, we provide with comparisons of the results to two different concepts of egalitarianism.

2 GAMES AND HIGH SEAS FISHERIES

2.1 Definitions of Transboundary Resources
Transboundary fishery resources are divided into two categories. The first contains the shared fish stocks which are found only inside the Exclusive Economic Zones of the coastal fishing nations. These resources have been thoroughly investigated (see for example Kaitala and Pohjola 1988). The second category consists of the straddling and highly migratory stocks, a part of which is found adjacent to the EEZ, ie in the high seas area. These fish stocks are the central concern of this paper.

2.2 Management of Straddling and Highly Migratory Fish Stocks
Let us next consider the multilateral conservation and management of straddling stocks by a regional fisheries organisation. Assume in particular that the regional organisation is composed of the coastal state, C, and two distant water fishing nations (DWFNs), D₁ and D₂, interested in developing an effective program for the conservation and
management of the straddling or highly migratory stock. We assume here that these three Charter Members are the only nations present in this negotiation process. We have in mind here a simple model of the fishery like in Clark & Munro (1975).

Let us assume for the sake of argument that the unit costs of harvesting for the countries are as follows $c_C < c_{D_2} < c_{D_i}$. That is, the fishing fleet of the coastal state is more efficient than the fleet of the distant water fishing nation. Assuming that the optimal stock level for the coastal state $C$ is higher than the bionomic equilibrium for the DWFNs, it then follows that

\begin{equation}
 x_{D_2}^\infty < x_{D_i}^\infty < x_C^*
\end{equation}

In this special case, the structure of the game leads to a situation where the Nash non-cooperative feedback equilibrium solution is such that the resource will be depleted in a most rapid approach manner until level $x_{D_2}^\infty$ has been reached (Clark 1980, Kaitala 1989). More generally the non-cooperative feedback strategies of the three nations are defined as

\begin{equation}
 E_C^N(x) = \begin{cases} 
 E_C^{\max}, & x > \min(x_C^*, x_{D_1}^\infty, x_{D_2}^\infty) = x_{D_2}^\infty \\
 F(x)/x, & x = \min(x_C^*, x_{D_1}^\infty, x_{D_2}^\infty) = x_{D_2}^\infty \\
 0, & x < \min(x_C^*, x_{D_1}^\infty, x_{D_2}^\infty) = x_{D_2}^\infty 
\end{cases}
\end{equation}

\begin{equation}
 E_{D_i}^N(x) = \begin{cases} 
 E_{D_i}^{\max}, & x > x_{D_i}^\infty \\
 0, & x \leq x_{D_i}^\infty 
\end{cases}
\end{equation}
Thus, the straddling stock will be subject to overexploitation if non-cooperation prevails. Note that the outcome is virtually identical to that of an unregulated open access fishery.

We next turn to study the cooperative conservation and management of a straddling/highly migratory stock by the three Charter Members. As in Kaitala and Munro (1995), we continue to assume that cooperative agreements upon being achieved are binding, and that side payments among the players are a feasible policy instrument.

In Kaitala and Pohjola (1988), it is shown that in this setting the more efficient state will buy out the distant water fishing fleets. Furthermore, the cooperative arrangement will be focused on the sharing of the total net returns from the fishery among Charter Members. In the current paper, we adopt this view of cooperative agreements i.e. when sharing the benefits from the cooperative agreement we assume that the countries have sold their fishing rights to the most efficient Member.

Let \( w[x(0)] \) denote the present value of the net economic return from the fishery at the stock level \( x(0) \), upon following the optimal harvest strategy of the coastal state. This choice of strategy would maximise the net returns from the fishery if managed by a sole owner, since the unit costs of harvesting are the lowest for the coastal state. Let \( w_C[ x(0) ] \), \( w_{D_1}[ x(0) ] \) and \( w_{D_2}[ x(0) ] \), respectively, denote the shares of countries C, D\(_1\), D\(_2\) of the aforementioned global net economic return from the fishery under a cooperative agreement. We have

\[
(4) \quad w[ x(0) ] = w_C[ x(0) ] + w_{D_1}[ x(0) ] + w_{D_2}[ x(0) ]
\]

That is, the shares are Pareto-efficient: if one player gains access to a greater benefit, the other players will necessarily gain less.

Each Charter Member expects to receive at least its threat payoff, that is, the payoff corresponding to the payoff available from the non-cooperative resource use. Otherwise, there is no individual reason for a Member to accept or to obey the agreement. Let
\( e[x(0)] \) denote the global net returns to be shared among the Charter Members. These are equal to the present value of harvesting using the strategy of the coastal state less the sum of the threat payoffs

\[
(5) \quad e[x(0)] = w[x(0)] - \sum_{C,D_1,D_2} J_i[x(0), E^N_C, E^N_{D_1}, E^N_{D_2}] 
\]

The threat payoffs are the economic returns from the fishery that the countries will receive if they follow the non-cooperative Nash strategies described in equations (2) and (3).

An application of the Nash bargaining scheme (1953) gives the result that, under the transfer payment regime, the global net returns be split equally between the Charter Members (Kaitala and Munro 1995). The cooperative net revenue that Charter Member \( i \) will receive is then equal to

\[
(6) \quad w_i[x(0)] = e[x(0)]/3 + J_i[x(0), E^N_C, E^N_{D_1}, E^N_{D_2}], \quad i = C,D_1,D_2
\]

This result will hold true even if the Charter Members are economically different. The rationale in applying the Nash bargaining scheme is that when joining the agreement each Charter Member can be seen to make an equal contribution to reaching the agreement and to generating the subsequent economic benefits.\(^2\)

### 3 APPLYING CHARACTERISTIC FUNCTION GAMES TO STRADDLING AND HIGHLY MIGRATORY STOCKS

We showed in Section 2 that the benefits should be shared equally between all three players when transfer payments are feasible and the Nash bargaining scheme is applied. Another view on the negotiation problem can be obtained by applying the characteristic function approach, which can also be used to define a fair way to allocate extra benefits of cooperation between the fishing nations. Next we attempt to determine contributions

\(^2\) See Munro (1979) and Kaitala & Pohjola (1988) for interpretations and further references.
of the players to each possible coalition when sharing the benefits. We assume transferable utility ie allow for side payments.

3.1 Structure of the Game

In a characteristic function game setting, the number of coalitions is $2^m$, where $m$ is the number of players. Thus, in the case of straddling fish stocks with three players the possible eight coalitions are $\{\{C, D_1, D_2\}, \{C, D_1\}, \{C, D_2\}, \{D_1, D_2\}, \{C\}, \{D_1\}, \{D_2\}, \emptyset\}$.

The theory of c-games is based on the fundamental assumption that the players have already agreed to cooperate with one another. Thus the grand coalition, including all players, exists at the beginning of the game. The problem to be solved is the distribution of benefits of cooperation in a fair way. We attempt to find out whether there exists a coalition which could give greater benefits to its members than the grand coalition. We show that there exists no such coalition, and that the distribution of benefits differs from that obtained above (see equation 6).

Strategies are of less direct interest in c-games. Instead, we are interested in the payoff opportunities achievable by the players. The structure of the high seas fishery game will be described below in the characteristic function or coalitional form. The total benefit of cooperation compared to the threat point payoffs is given by (5).

Let $\Gamma(M,v^*)$ denote the characteristic function form of the game, where $v^*(\{K\})$ is the value of coalition $K$ ie it measures the payoff possibilities achievable by coalition $K$, and $M$ is the set of players (Schmeidler 1969).

Then the payoff achievable by the grand coalition is

(7) $v^*(M) = e [ x(0) ]$
For a single fishing nation, the benefit from cooperation is zero because no benefits from cooperation exist. In this kind of situation, all three nations play against each other, which is obviously similar to the non-cooperative game described by equations (2) and (3). For the two-player coalitions, we assume that they have to play non-cooperatively with the third fishing nation. This means that no single fishing nation could be excluded from fishing activities by a group of other fishing nations. The countries outside coalition K affect the coalition’s payoff through $J_{\{K\}}$ as is shown for the coalition $\{D_1, D_2\}$

$$J_{\{D_1,D_2\}} = \int_0^{T_2} e^{-rt} \left[ px(t) - c_{D_2} \right] E^{\text{max}}_{D_2} dt + \int_0^{T_1} e^{-rt} \left[ px(t) - c_{D_1} \right] E^{\text{max}}_{D_1} dt$$

such that $dx/dt = F(x) - Ex$, where $E = \sum_{i=1,2,3} E^{\text{max}}_i$ (note that this holds only when all countries are harvesting), and $T_2$ denotes the moment when $x = x_{D_2}^\infty$ and $T_1$ an earlier moment when $x = x_{D_1}^\infty$. The coalition will choose the same strategies as in the situation of three-player non-cooperation, because it does not benefit from letting $D_2$ act as a sole owner due to the coastal state's strategy to overharvest the fish stock using the most rapid approach, as described in (2). The same reasoning can be applied to other coalitions.

For the two-player coalitions, the benefits of cooperation $v^*([K])$ are defined by its payoff $J_{\{K\}}$ subtracted with the sum of the non-cooperative payoffs of its members (see Mesterton-Gibbons 1992).

(9a) \[ v^*([D_1, D_2]) = J_{\{D_1, D_2\}}\left[ x(0) \right] - \sum_{D_1, D_2} J_i \left[ x(0), E^N_C, E^N_{D_1}, E^N_{D_2} \right] \]

(9b) \[ v^*([C, D_2]) = J_{\{C, D_2\}}\left[ x(0) \right] - \sum_{C, D_2} J_i \left[ x(0), E^N_C, E^N_{D_1}, E^N_{D_2} \right] \]
Note further, that the surplus benefits of the coalitions $v^*({K})$ are evaluated at $x(0)$ ie at the beginning of the negotiations.

Let us next define the normalised characteristic function. The normalised c-function is defined by

\begin{equation}
(10) \quad v(K) = \frac{v^*(K)}{\sum_{C,D_i} J_i \left[ x(0), E^N_C, E^N_{D_1}, E^N_{D_2} \right]}
\end{equation}

Thus the normalised benefit for the grand coalition is one, and for the other coalitions less than one. Note that this means that our game is essential, $v(M) > 0$. The normalised c-function gives the bargaining strengths of each coalition. The greater the value of $v(K)$ the stronger the coalition's bargaining strength.

Now consider the coalition $\{D_1, D_2\}$. In this situation, the more efficient country $D_2$ could buy out $D_1$ in order to guarantee maximum benefits from the fishery. But the coalition has to play against the coastal state, $C$, whose threat point is below the threat points of the distant water fishing nations. Thus the coastal state increases its fishing effort, and the stock will be depleted to level $x_{D_2}^\infty$ (see equations 2 and 3). As a consequence, the coalition has no bargaining strength

\begin{equation}
(11a) \quad v(\{D_1, D_2\}) = 0
\end{equation}

Similarly in the case of coalition $\{C, D_1\}$, the more efficient distant water fishing nation is able to compete until $x_{D_2}^\infty$ is reached, and thus

\begin{equation}
(11b) \quad v(\{C, D_1\}) = 0
\end{equation}
The coalition \( \{C, D_2\} \) differs from the other two-player coalitions because they only have to harvest the fish stock to the level \( x_{D_1}^\infty \) and this level is larger than the threat point stock level as can be seen from (1). Thus the coalition could be better off than in the threat point, and its bargaining strength is positive

\[(11c) \quad v(\{C, D_2\}) > 0\]

### 3.2 Applying the concepts of C-games

Now that we have defined the structure of our high seas fishery game, we are ready to consider a solution for the game. Our task is then to determine an "imputation" vector \( z = (z_C, z_{D_1}, z_{D_2}) \) that is fair in some appropriate way. This would mean that the countries are willing to enter an agreement voluntarily, because they would be satisfied with their share of the surplus benefits from cooperation.

The set of all imputations is \( Z \). \( \sum_{i \in K} z_i \) is said to be coalition \( K \)'s allocation at \( z \). The imputation vector is individually rational if \( z_i \geq 0 \). Thus, each player expects to receive at least some benefits from cooperation and the whole set of players shall divide all of the benefits with each other. Equations (9) and (14) together guarantee that \( z_i \geq 0 \) is a sufficient condition for the fishing nations to receive at least their threat point payoff.

We next turn our attention to the classical concept of the core of the game. The core is defined for c-games with the help of the concept of the excess, which is given as

\[(12) \quad e(K, z) = \sum_{i \in K} z_i - v(K)\]

If \( e(K, z) < 0 \), then the players in the coalition \( K \) view the imputation as unfair because they could do better if they did not have to form the grand coalition. Therefore these imputations are excluded, and the remaining imputations form the core of the game \( \Gamma(\{C, D_1, D_2\}, v) \). Thus, the core consists of all the imputations for which the excess is positive. It is noted here that the core is a subset of the reasonable set if the core exists.
The excess for the grand coalition is defined by $e(M, z) = 0$. This means that because the grand coalition always gets all benefits from cooperation and it is also generating the maximum amount of surplus benefits, it cannot be neither satisfied or dissatisfied with the chosen imputation. The excesses for the single-player coalitions and for the coalitions, in which $D_1$ is a member are equal to their imputations. For the coalition $\{C, D_2\}$ the excess is

$$(13a) \quad e(\{C, D_2\}, z) = z_C + z_{D_2} - v(\{C, D_2\})$$

and to the other coalitions

$$(13b) \quad e(\{C, D_1\}, z) = z_C + z_{D_1}$$

$$(13c) \quad e(\{D_1, D_2\}, z) = z_{D_1} + z_{D_2}$$

$$(13d) \quad e(\{i\}) = z_i$$

The excess measures the attitude of the coalition to a suggested payoff vector. The smaller is the excess the more strongly the coalition objects to a given imputation $z$ (Schmeidler 1969).

It is generally assumed for c-games that the players in the coalitions can achieve greater benefits through cooperation, that is, for all coalitions $S$ and $T$ we have

$$(14) \quad v(S \cup T) \geq v(S) + v(T) - v(S \cap T)$$

This convexity condition is a sufficient (but not necessary) condition for the core to exist, in which case the game is said to be proper. The obvious question then arises whether the core exists in our fishery game, or does our proposed solutions lie in the core? The answer to the first question is positive, as seen in figure 1. We shall provide
with an answer to the latter question when considering the Shapley value, which will be shown to lie in the core.

In the c-game with three players we can illustrate these concepts with a following picture. The vertical and horizontal axes are drawn as usual in figure 1, but the axis for $D_1$ is drawn to aid the illustration of the core and the reasonable set. It is drawn in figure 1 for a special case, where $C$ and $D_2$ receive an equal share of the benefits. If for example we should allocate all benefits to $C$, then we should draw the axis for $D_1$ by beginning at the point $(1,0)$ towards $(0,0)$. Thus the point $(1,0,0)$ would coincide with $(1,0)$.

![Figure 1: Imputations and core in a high seas fishery c-game](image)

The core is represented as the shaded area in figure 1. Note that this area is equivalent to equation (13a) being positive.

4 SEARCHING FOR A FAIR SOLUTION: THE NUCLEOLUS
The advantage of the nucleolus is that it has just one point, which gives the fairest imputation. The idea of the nucleolus is to find a payoff vector whose excesses for all coalitions are as large as possible. This means that the benefit of the least satisfied coalition is maximised. The nucleolus belongs to every non-empty rational ε-core and it produces one outcome at most, if the set of imputations is convex. There exist a number of other cooperative solution concepts, such as the bargaining set and the kernel, which usually include the nucleolus, and therefore Schmeidler (1969) sees it as a product of third stage development of solution concepts.

Comparing the excesses of coalitions is done with the aid of function

\[ \theta(u) = \left[ \theta_1(u), \theta_2(u), \ldots, \theta_n(u) \right] \]

and the ordering of coalitions is as follows

\[ \theta_j(u) = e(K_j, u) \quad \text{and} \quad \theta_j(u) \leq \theta_{j+1}(u) \]

Thus the \( j \)th component of \( \theta(u) \) is at the same time the \( j \)th smallest excess relative to the payoff vector.

\( \theta(u) \) and \( \theta(u') \) are then compared by using the lexicographic ordering, which states that \( \theta(u) > \theta(u') \), if \( \theta_1(u) > \theta_1(u') \) or, for \( j>1 \) \( \theta_j(u) > \theta_j(u') \) and \( \theta_i(u) = \theta_i(u') \) for \( i \neq j \). This relation is denoted \( \theta(u) >_L \theta(u') \).

Using the lexicographic ordering the nucleolus is then given by

\[ \text{nuc}(Z) = \{ u \in Z \mid u' \in Z \text{ implies } \theta(u) >_L \theta(u') \} \]

This proposed payoff vector belongs to the set of imputations and maximises the minimum satisfaction over all coalitions. It is therefore viewed as a fair solution concept. (Friedman 1991)
As the grand coalition's excess (and $\emptyset$'s) is usually expected to be zero ($\sum z_i = 1 = v(M)$, then $e(M, z) = 0$), the remaining task is to find an imputation that would maximise the most dissatisfied two-country coalition's or single fishing nation's excess. That is

$$\theta(z^*) = (0, 0, e(K, z^*), e(\{i\}, z^*)), \quad \theta(z^*) > L \theta(z') \quad \forall z' \neq z^*$$

where $K = \{\{C, D_1\}, \{C, D_2\}, \{D_1, D_2\}\}$, and $i = \{\{C\}, \{D_1\}, \{D_2\}\}$

The obvious question is, what kind of imputation does the nucleolus offer for the case of the high seas fishery game?

The excesses are given by (13). Suppose now that $v(\{C, D_2\}) = 0$. Then obviously the nucleolus would give a similar result to the Nash bargaining scheme, namely to divide the surplus benefits equally between the fishing nations.

If $v(\{C, D_2\}) = 1$, then we should give the coalition $\{C, D_2\}$ all of the benefits to ensure a positive excess to this coalition. This result differs from the egalitarian Nash bargaining solution. The benefits should always be shared equally between C and $D_2$, because if the other country receives less benefits it will be more dissatisfied than the other. The same reasoning can also be applied to coalitions $\{C, D_1\}$ and $\{D_1, D_2\}$.

If $v(\{C, D_2\}) = 1/2$, then we could make the coalition $\{C, D_2\}$ satisfied by giving it $3/4$ and $D_1$ by giving it $1/4$, because both coalitions would then have an excess of $1/4$. The other coalitions would have even larger excesses. But if $v(\{C, D_2\}) \leq 1/3$, then we should give $D_1$ more than $1/3$ of the total surplus benefits, and this would make the other nations more dissatisfied. Thus, we can conclude that in the case where the coalition $\{C, D_2\}$ has only little bargaining power, the nucleolus gives the same result as the Nash bargaining solution, to share the benefits equally between all fishing nations.
If $v(\{C, D_2\}) > 1/3$, then we should share the benefits from cooperation by the following rule

\begin{align}
(19a) \quad & z_C = z_{D_2} = (v(\{C, D_2\})/2 + 1/2)/2 \\
(19b) \quad & z_{D_1} = 1/2 - v(\{C, D_2\})/2
\end{align}

The rationale behind (19) is as follows: when $v(\{C, D_2\})$ is large the excesses of the coalition $\{C, D_2\}$ and $\{D_1\}$ become critical, i.e., their values are the smallest. The nucleolus is then derived by setting these excesses, $e(\{C, D_2\}, z)$ and $e(\{D_1\}, z)$, equal. If the other is smaller, then this coalition is more dissatisfied and we are able to find a fairer imputation. We can thus conclude, that as the bargaining power of $\{C, D_2\}$ decreases, the nucleolus approaches the egalitarian Nash bargaining solution.

Using the lexicographic notation we can describe the situation in the management of high seas fisheries as follows.

\begin{equation}
(20) \quad \theta(u) = (\{D_1\}, \{C, D_2\}, \{C\}, \{D_2\}, \{D_1, D_2\}, \{C, D_1\})
\end{equation}

The excesses for $\{D_1\}$ and $\{C, D_2\}$ are the smallest, for $\{C\}$ and $\{D_2\}$ it is equal and for the two-player coalitions $\{D_1, D_2\}$ and $\{C, D_1\}$ the excesses are the largest, respectively.

**5 DISCUSSION AND CONCLUSIONS**

In this paper, we have carried out an analysis of the optimal management of straddling fish stocks using a characteristic function approach. By making use of a solution concept, the nucleolus, we have shown that the most efficient fishing coalition should receive a larger share of the benefits only if it is sufficiently efficient. The intuition behind this result is that it is not fair to reward small differences in the contributions to the common benefit from cooperation. This scheme may provide a more stable basis for regional cooperation since the least efficient countries receive nearly as much of the
surplus benefits as the most efficient fishing nation when differences in the unit costs of harvesting are small between the countries involved. Furthermore, the more efficient fishing nations receive more of the gains of cooperation than the less efficient when there are large differences in the unit costs.

The surplus benefits of cooperation for coalition \{C, D_2\} determine the major results of the current paper. This term, \(v(\{C, D_2\})\), can be traced back to equation (9b) and (10), where it is normalised with respect to the payoff of the grand coalition. Therefore, its value is smaller than one, and increasing as the unit costs of fishing for the least efficient DWFN increases. Condition \(v(\{C, D_2\}) > 0\) means that the two most efficient countries could benefit from having a common fisheries policy. The higher the value of \(v(\{C, D_2\})\), the more beneficial this policy would be to these countries.

It is interesting to notice that in our game the nucleolus is more egalitarian in the sense of equality of total benefits (that is, one third to every fishing nation) than the Shapley value\(^3\): the nucleolus gives an allocation \([1 - v(\{C, D_2\})] / 2\) to the least efficient member of the fisheries organisation, and \(1 / 3\) if \(v(\{C, D_2\}) \leq 1 / 3\), whereas the Shapley value gives only \([1 - v(\{C, D_2\})] / 3\) even if the coalition \{C, D_2\} has very little bargaining power.

If \(v(\{C, D_2\}) > 1 / 3\), then the differences between imputations given by the Shapley value and the nucleolus are

\[
(21a) \quad 1/12 - v(\{C, D_2\})/12 > 0
\]

for the coastal state and the more efficient DWFN \(D_2\), and

\[
(21b) \quad -1/6 + v(\{C, D_2\})/6 < 0
\]

\(^3\) See Kaitala and Lindroos (1997a,1997b) for the derivation of the Shapley value imputations: 
\(z^S_C = v(\{C, D_2\})/6 + 1/3, \quad z^S_{D_2} = v(\{C, D_2\})/6 + 1/3, \quad z^S_{D_1} = [1 - v(\{C, D_2\})]/3\)
for the less efficient DWFN, D₁. Because (21a) is positive for C and D₂ the Shapley value gives them a larger share of the benefits than the nucleolus. Similarly, since (21b) is negative D₁ is better off by the solution given by the nucleolus.

If \( v(\{C, D₂\}) < 1/3 \), then the differences between imputations given by the Shapley value and the nucleolus are

\[
\text{(22a) } \frac{v(\{C, D₂\})}{6} > 0
\]

for the coastal state and the more efficient D₂, and

\[
\text{(22b) } -\frac{v(\{C, D₂\})}{3} < 0
\]

for the less efficient D₁. Thus as the value of the most efficient fishing coalition approaches 1, in the case \( v(\{C, D₂\}) > 1/3 \), the imputation given by the nucleolus approaches the Shapley value, and the nucleolus gives in both cases a more egalitarian allocation of surplus benefits than the Shapley value.

As pointed out by Mesterton-Gibbons (1993) the degree of egalitarianism may depend on whether egalitarian signifies equality of total benefits or equality of nonattributable benefits. Using this alternative concept of egalitarianism, it then follows that the Shapley value is always more egalitarian than the Nucleolus, the difference being more significant, the smaller the bargaining power of \( \{C, D₂\} \).

In our game, the nonattributable (remaining costs after the marginal costs of the countries involved) benefits are calculated as

\[
\text{(23) } 1 - (1 - 0) - (1 - v(\{C, D₂\})) - (1 - 0) = v(\{C, D₂\}) - 2
\]
Countries are then allocated an equal share of these nonattributable benefits plus their marginal benefits. This approach would give \((1 - 2v(\{C, D_2\}))/3\) to the least efficient fishing nation and \((1 + v(\{C, D_2\}))/3\) to members of the coalition \{C, D_2\} as an egalitarian imputation.

Using the second concept of egalitarianism, in the case when \(v(\{C, D_2\}) \leq 1/3\), the difference between the nucleolus and the egalitarian imputation\(^4\) is, for all countries (C, D_1, D_2), respectively

\[
(24a) \quad \left(\frac{v(\{C, D_2\})}{3}, -\frac{2v(\{C, D_2\})}{3}, \frac{v(\{C, D_2\})}{3}\right)
\]

For the Shapley value the difference is

\[
(24b) \quad \left(\frac{v(\{C, D_2\})}{6}, -\frac{v(\{C, D_2\})}{3}, \frac{v(\{C, D_2\})}{6}\right)
\]

Thus we see that the nucleolus is further away from the nonattributable egalitarian imputation, by a factor of 2.

For the other case, \(v(\{C, D_2\}) > 1/3\), we have the same difference with respect to the Shapley value, and for the nucleolus the difference is

\[
(25) \quad \left(\frac{1}{12} + \frac{v(\{C, D_2\})}{12}, -\frac{1}{6} - \frac{v(\{C, D_2\})}{6}, \frac{1}{12} + \frac{v(\{C, D_2\})}{12}\right)
\]

Because \(v(\{C, D_2\}) < 1\), we conclude that in the latter case, when the bargaining power of the most efficient coalition is higher than one third, the Shapley value is still more egalitarian in the sense of nonattributable benefits. Again we notice that as the value of coalition \{C, D_2\} approaches 1, the nucleolus approaches the Shapley value.

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\(^4\) Note that the difference between the Nash bargaining solution and the nonattributable egalitarian solution also equals (24a).
The result that the differences in the efficiencies of the fishing nations should be large in order to justify unequal distributions of the benefits from cooperation is interesting from a practical point of view. In this case, one could divide the nations into broad categories and this would not violate the fair distribution of benefits. The administrative costs would possibly be lower in such a situation. We should note, however, that our results depend on the cost structures of the fishing countries. If the unit costs of harvesting are equal to all nations or just for the DWFNs the sharing of the benefits should be equal.

Our analysis was based on the restrictive assumption of constant total costs and total effort for every coalition. Furthermore, the number of fishing nations were restricted to three and the effect of the sharing rule on the players' strategies was not considered. Of course the countries might be willing to re-negotiate their agreement at some point in time as, for example, the stock level changes. If these assumptions are relaxed the issue may become more complex. It would still be evident, however, that the equal sharing of benefits would not necessarily help to create an agreement on a voluntary basis.

REFERENCES


Mesterton-Gibbons, Michael [1992], *An Introduction to Game-Theoretic Modelling*, Addison-Wesley, California.


Nash, John [1953], *Two Person Cooperative Games*, Econometrica 21, 128-140.


Tulkens, Henry [1997], *Co-operation vs. Free Riding in International Environmental Affairs: Two Approaches*, Fondazione Eni Enrico Mattei working paper 47.97, Milano.