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MANAGEMENT OF REGIONAL FISHERIES ORGANISATIONS: AN APPLICATION OF THE SHAPLEY VALUE

Marko Lindroos

Helsinki University of Technology
Department of Engineering Physics and Mathematics
Systems Analysis Laboratory

Distribution:
Systems Analysis Laboratory
Helsinki University of Technology
P.O.Box 1100
FIN-02015 HUT, FINLAND
Tel. +358-9-451 3056
Fax. +358-9-451 3096
E-Mail: systems.analysis@hut.fi

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Abstract*. In this paper, we examine a game theoretic setting in which four countries have established a regional organisation for the conservation and management of straddling and highly migratory fish stocks as recommended by the United Nations Convention. These countries consist of two coastal states and two distant water fishing nations (DWFNs). A characteristic function game approach is applied to describe the sharing of the surplus benefits from cooperation. We are specifically interested in the effect of possible coalition restrictions on these shares. According to our results the distant water fishing nations, by refusing to join with the coastal states, can improve their negotiation position if their fishing costs are high. In addition, we are also allowing for unlimited number of fishing nations in the regional fisheries organisation. The veto players always receive an equal share of the benefits and the least efficient country is seen to make no contribution to the cooperative management regime.

Keywords: Coalitions, cooperative games, high seas fisheries, international environmental negotiations, Shapley value, straddling and highly migratory fish stocks

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1 INTRODUCTION[1]

In the early 17th century the problem of the high seas was solved by giving free access to fishermen from every country. At the time of the declaration of this "Mare Liberum" fisheries were much more abundant than they are today. Marine fish stocks have been declining during the latter part of the present century, and therefore we are now experiencing a rather different situation. There are now significant gains to be achieved from limiting the activities of fisheries.

From the freedom of the seas marine jurisdictions have begun expanding. During negotiations for the Law of the Sea Convention (1982) the limit of the coastal state jurisdiction (Exclusive Economic Zone = EEZ) was extended further to 200 nautical miles. Further extensions of jurisdictions were needed even after this limit since the problems of exploiting fish stocks crossing the boundaries of EEZs and high seas areas were increasing. Therefore the United Nations Convention on Straddling and Highly Migratory Fish Stocks (1995) has been trying to create new kind of regimes in the high seas.

In the current paper, we examine a game theoretic setting in which countries have established a regional organisation for the conservation and management of straddling and highly migratory fish stocks as recommended by the United Nations Convention. A characteristic function game approach (c-game) is applied to describe the sharing of the surplus benefits from cooperation. Our objective is not to model the endogenous formation of coalitions but rather to assume that a regional fisheries organisation has already been formed and concentrate on the sharing of benefits due to this cooperative organisation. There could be other nations involved in the fishery as well, but they are outside of this organisation. Hannesson (1997) discusses the implications of changing the number of players in a migratory fish setting.

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In Section 2 we provide a basic c-game model of high seas fisheries the assumptions of which are changed in Section 3. In Section 3.1 the formation of coalitions is restricted in a simple way and the Shapley value is calculated for three different cases. There are four countries which consist of two coastal states and two distant water fishing nations (DWFNs). Also in this Section we assume a predefined possibilities of coalitions since we just want to indicate that coalition restrictions may play a significant role during the negotiations for regional fisheries organisations. Another purpose of this paper is to extend the previous model by Kaitala and Lindroos (1997) by allowing for unlimited number of fishing nations in the regional fisheries organisation (RFO). The Shapley value for this n-player case is derived in Section 3.2.

The economics of straddling stocks have been analysed earlier by Kaitala & Munro (1995 & 1997), Kaitala & Lindroos (1997) and Naito & Polasky (1997). The coalitional bargaining approach has been used in transboundary pollution models by, for example, Chander & 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.

2 BASIC C-GAME MODEL

We next review the results obtained when using the coalitional bargaining approach in a three-player game (Kaitala and Lindroos 1997). Here we restrict our attention to the Shapley Value (1953) and compare it to the Nash bargaining solution.

The characteristic function game (c-game) approach (Mesterton-Gibbons 1992) assumes a rather different perspective from the Nash bargaining approach (1953): 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. Thus, it is natural that the result of the two-player c-game coincides with the Nash bargaining solution. In our three-player game, 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. In addition, we continue assuming transferable utility ie allowing for side payments.

Consider a regional fisheries organisation with three members such that their unit costs[2] c_i of harvesting the fish stock are given below by equation (2.3). Note that we have in mind here a simple bioeconomic model as in Clark & Munro (1975):

$$(2.1) \quad \max\ J(x_0, E_i) = \int_0^{\infty} e^{-rt} \left[\, px(t) - c_i \,\right] E_i(t)\ dt$$

$$(2.2) \quad \text{s.t.} \quad dx/dt = F(x) - \Sigma_{i=1,2,3} E_i x, \qquad i = C, D_1, D_2$$

$$(2.3) \quad c_C < c_{D_1} < c_{D_2}$$

$$(2.4) \quad x_{D_1}^{\infty} < x_{D_2}^{\infty} < x_C^{*},$$

where p denotes the price (which is assumed constant), x(t) is the fish stock, E_i is the fishing effort of country *i*, harvesting of country *i* is given by $h_i = E_i x$ and F(x) is the standard compensatory growth function. The bionomic equilibrium x_i^{∞} denotes the stock level at which harvesting is no longer profitable to country *i*. Finally x_C^{*} is the optimum stock level for the coastal state.

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 $x_{D_1}^{\infty}$, where it is only profitable for the coastal state to continue exploiting the fish stock, has been reached (Clark 1980). More generally the non-cooperative feedback strategies of the three nations are defined as

[2] It should be noted here that the unit costs of fishing may be equal for the countries whereas the average costs of fishing are different.

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

(2.6) $$E_{D_i}^N(x) = \begin{cases} E_{D_i}^{\max}, & x > x_{D_i}^\infty \\ 0, & x \le x_{D_i}^\infty \end{cases}$$

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.

Let e[x(0)] denote the global net returns to be shared among the members. These are equal to the present value of harvesting using the strategy of the coastal state less the sum of the threat payoffs

(2.7) $$e\left[\, x(0) \,\right] = w\left[\, x(0) \,\right] - \sum_{C, D_1, D_2} J_i \left[\, x(0), E_C^N, E_{D_1}^N, E_{D_2}^N \,\right]$$

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

(2.8) $$w_i[x(0)] = e[x(0)]/3 + J_i\left[x(0), E_C^N, E_{D_1}^N, E_{D_2}^N\right], \; i = C, D_1, D_2$$

In order to apply the Shapley value we need to define the characteristic function for our game. The value of the grand coalition M is equal to the excess

(2.9) $$v(M) = e\,[\, x(0) \,]$$

Following Kaitala and Lindroos (1997) we notice that the only other coalition with positive bargaining strength is {C, D_1}. They only have to harvest the fish stock to the level $x_{D_2}^{\infty}$ and this level is larger than the threat point stock level as can be seen from (2.4). Thus the coalition could be better off than in the threat point, and its bargaining strength is positive[3]. Equation (2.10) gives this coalition's payoff when playing non-cooperatively against D_1.

$$\text{(2.10)} \qquad J_{\{C,D1\}} = \int_0^T e^{-rt}\left[px(t) - c_{D_1}\right]E_{D_1}^{\max} + \left[px(t) - c_C\right]E_C^{\max} dt$$

Here T denotes the moment when x = $x_{D_2}^{\infty}$. After T, E_{D1} = 0 and E_{D2} can be reduced just to maintain the level x = $x_{D_2}^{\infty}$. Note, that we assume that each nation *i* is able to deplete the stock down to x_i^{∞}, that is $E_i^{\max}$ is large. This is a reasonable assumption since many of the world's fisheries suffer from heavy overcapacity.

With the aid of (2.10) we can then define,

$$\text{(2.11)} \qquad v(\{C, D_1\}) = \frac{J_{\{C,D_1\}}\left[\, x(0)\,\right] - \sum\limits_{C,D_1} J_i\left[\, x(0), E_C^N, E_{D_1}^N, E_{D_2}^N\,\right]}{w\left[x(0)\right] - \sum\limits_{C,D_1,D_2} J_i\left[x(0), E_C^N, E_{D_1}^N, E_{D_2}^N\right]},$$

where the numerator expresses the worth of coalition {C, D_1} and the denominator the total benefits from cooperation. J_i denotes the Nash payoffs for the fishing nations, $w\left[x(0)\right]$ the present value of the net economic return from the fishery upon following the optimal harvest strategy of the coastal state.

[3] Note that we have an implicit assumption for entry/exit to/from the fishery. When the country is earning negative profits it immediately exits the fishery and vice versa.

In this case, the Shapley value gives more than one third of the benefits (as the Nash bargaining solution would suggest) to the two most efficient countries, C and D_1:

$$(2.12) \quad z_C^S = z_{D_1}^S = v(\{C, D_1\})/6 + 1/3$$

$$(2.13) \quad z_{D_2}^S = [1 - v(\{C, D_1\})]/3,$$

where $v(\{C, D_1\})$ denotes the value of the coalition of the two most efficient fishing nations when playing non-cooperatively against the third nation. Note, that e(x(0)) is normalized to one and $v(\{C, D_1\}) < 1$.

The fairness of the Shapley value arises from the equal treatment of countries in the coalition formation process as well as from the difference of the bargaining strengths between the coalitions of which the country is a member and those of which it is not a member.

3 EXTENSIONS OF THE THREE-PLAYER MODEL

3.1 Restricted Coalitions

We assume that coalition formation is restricted (see for example Derks & Peters 1993) as follows. Coastal states can form a joint coalition and DWFNs can also join together. That is, feasible coalitions are: $\{C_1, C_2\}$ and $\{D_1, D_2\}$. The reason for this sort of division arises from the actual negotiations for the United Nations Agreement on Straddling and Highly Migratory Fish Stocks (1995). The interests of the coastal states and distant water fishing nations have been often conflicting.

We apply a very simple method of coalition restriction according to which the value of a restricted coalition is zero in the characteristic function. We then show by comparing unrestricted and restricted Shapley values that if the DWFNs are inefficient enough they gain by refusing to form coalitions with the coastal states. We proceed by comparing three interesting cases where the unit costs of fishing vary between the members. The first case gives a larger share of benefits to both DWFNs with coalition restrictions if the efficiency difference between the DWFNs is not remarkably large. The second case gives a larger total share of benefits to the DWFNs - the more efficient country receives a smaller share and the less efficient receives a larger share with coalition restrictions but together they are better off. The third case always gives a smaller share to the DWFNs.

Case I

The fishing costs and bionomic equilibrium levels of the countries are as follows

(3.1a) $c_{C_1} < c_{C_2} < c_{D_1} \leq c_{D_2}$

(3.1b) $x^{\infty}_{C_2} < x^{\infty}_{D_1} \leq x^{\infty}_{D_2} < x^{*}_{C_1}$

Let us first concentrate on the subcase where $c_{D_1} = c_{D_2}$ and $x^{\infty}_{D_1} = x^{\infty}_{D_2}$. Due to coalition restrictions only v({C_1, C_2}) > 0. This yields the restricted Shapley value imputations for the countries, respectively

(3.2a) $z^{S_R}_{C_1} = z^{S_R}_{C_2} = 1/4 + v(\{C_1, C_2\})/12$

(3.2b) $z^{S_R}_{D_1} = z^{S_R}_{D_2} = 1/4 - v(\{C_1, C_2\})/12$

In the unrestricted situation, also v({C_1, C_2 , D_i}) > 0. Furthermore, we observe that v({C_1, C_2 , D_1}) = v({C_1, C_2 , D_2}) = v({C_1, C_2}) , which is reasonable since the DWFNs do not contribute anything to the cooperation. Then it follows that in the unrestricted situation the Shapley imputations are given as

(3.3a) $z^{S}_{C_1} = z^{S}_{C_2} = 1/4 + v(\{C_1, C_2\})/4$

(3.3b) $z^S_{D_1} = z^S_{D_2} = 1/4 - v(\{C_1, C_2\})/4$

We see immediately that restrictions in the coalition formation benefit the DWFNs since their share in the unrestricted situation is smaller than in the restricted situation. The difference between the restricted and the restricted Shapley values for the DWFNs is given by

(3.4) $z^{S_R}_{D_i} - z^S_{D_i} = v(\{C_1, C_2\})/6$

Thus, by joining together even the countries that have only a small amount of bargaining power can considerably improve their negotiation position by refusing to cooperate with the most efficient nations. This is probably one of the reasons for what has actually happened during the negotiations for the straddling and highly migratory fish stocks in the United Nations.

Let us next investigate the subcase for which $c_{D_1} < c_{D_2}$ and $x^\infty_{D_1} < x^\infty_{D_2}$. The restricted imputations are the same as in equation (3.2) since v({D_1, D_2}) is still zero. In the unrestricted situation we have
v({C_1, C_2, D_1}) > v({C_1, C_2}) = v({C_1, C_2, D_2}). The unrestricted Shapley value for this subcase is the following

(3.5a) $z^S_{C_1} = z^S_{C_2} = 1/4 + 1/12\left[v(\{C_1, C_2, D_1\}) + v(\{C_1, C_2\}) + v(\{C_1, C_2, D_2\})\right]$

$= 1/4 + 1/12 v(\{C_1, C_2, D_1\}) + 1/6 v(\{C_1, C_2\})$

(3.5b) $z^S_{D_1} = 1/4 - v(\{C_1, C_2, D_2\})/4 + 1/12\left[v(\{C_1, C_2, D_1\}) - v(\{C_1, C_2\})\right]$

$= 1/4 - v(\{C_1, C_2\})/3 + 1/12 v(\{C_1, C_2, D_1\})$

(3.5c) $z^S_{D_2} = 1/4 - v(\{C_1, C_2, D_1\})/4$

The differences for the DWFNs are given by

$$(3.6a) \quad z_{D_1}^{S_R} - z_{D_1}^{S} = v(\{C_1, C_2\})/6 + v(\{C_1, C_2, D_2\})/4 - v(\{C_1, C_2, D_1\})/12$$

$$= 5v(\{C_1, C_2\})/12 - v(\{C_1, C_2, D_1\})/12$$

$$(3.6b) \quad z_{D_2}^{S_R} - z_{D_2}^{S} = v(\{C_1, C_2, D_1\})/4 - v(\{C_1, C_2\})/12$$

We notice that D_2 still gets a larger share under restriction because we assumed $v(\{C_1, C_2, D_1\}) > v(\{C_1, C_2\})$. But the same does not necessarily apply to D_1. In order to (3.6a) being negative $v(\{C_1, C_2, D_1\})$ should be five times bigger than $v(\{C_1, C_2\})$. Therefore, our result from Case I, the unwillingness of DWFNs to join coalitions with coastal states, applies only to the case where the efficiency difference of the DWFNS is not large. Otherwise, the more efficient DWFN seems to have an incentive to join with a coastal state, after all. Intuitively put, we do not expect countries with very different economic structures to cooperate.

<u>*Case II*</u>

$$(3.7a) \quad c_{C_1} < c_{D_1} \le c_{C_2} \le c_{D_2}$$

$$(3.7b) \quad x_{D_1}^{\infty} \le x_{D_2}^{\infty} \le x_{C_2}^{\infty} < x_{C_1}^{*}$$

Thus, C_1 and D_1 are veto players in the sense that both countries are needed for a particular coalition to have positive worth or bargaining strength (see Arin & Feltkamp). It follows that $v(\{C_1, D_1, C_2\}) \ge v(\{C_1, D_1\}) = v(\{C_1, D_1, D_2\}) > 0$, but these coalitions are restricted by assumption. Therefore, the allocation of benefits is the equal split solution shown in equation (2.8) for the restricted Shapley value. In fact, this result applies to all the restricted cases where one of the DWFNs is a veto player.

If $c_{D_1} = c_{C_2} < c_{D_2}$ only $v(\{C_1, D_1, C_2\}) > 0$ and the unrestricted Shapley are then given by

(3.8a) $z^S_{D_1} = 1/4 + 1/12 v(\{C_1, D_1, C_2\}) = z^S_{C_1} = z^S_{C_2}$

(3.8b) $z^S_{D_2} = 1/4 - 1/4 v(\{C_1, D_1, C_2\})$

Let us next compare the sum of restricted and unrestricted Shapley values for the DWFNs.

(3.9) $\sum z^{S_R}_{D_i} - \sum z^S_{D_i} = v(\{C_1, D_1, C_2\})/6$

Thus, we see that together the DWFNs could be better off by restricting coalition formation since equation (3.9) is positive.

If $c_{D_1} < c_{C_2} < c_{D_2}$ then we have $v(\{C_1, D_1, C_2\}) > v(\{C_1, D_1\}) = v(\{C_1, D_1, D_2\})$ and the unrestricted Shapley values are

(3.10a) $z^S_{D_1} = 1/4 + 1/12\left[v(\{C_1, D_1, C_2\}) + v(\{C_1, D_1\}) + v(\{C_1, D_1, D_2\})\right] = z^S_{C_1}$

(3.10b)

$$z^S_{C_2} = 1/4 + 1/12\left[v(\{C_1, D_1, C_2\}) - v(\{C_1, D_1\}) + v(\{C_1, D_1, D_2\})\right] - 1/4 v(\{C_1, D_1, D_2\})$$
$$= 1/4 + 1/12 v(\{C_1, D_1, C_2\}) - 1/3 v(\{C_1, D_1\})$$

(3.10c) $z^S_{D_2} = 1/4 - 1/4 v(\{C_1, D_1, C_2\})$

The difference between the sum of restricted and unrestricted Shapley values for the DWFNs is given by

$$(3.11)\ \sum z_{D_i}^{S_R} - \sum z_{D_i}^{S} = v(\{C_1, D_1, C_2\})/4 - \left[2v(\{C_1, D_1\}) + v(\{C_1, D_1, C_2\})\right]/12$$

Equation (3.11) is always positive since $v(\{C_1, D_1, C_2\}) > v(\{C_1, D_1\})$. Thus, we see that again the DWFNs could be better off together by restricting coalition formation.

Finally, if $c_{D_1} < c_{C_2} = c_{D_2}$ then only $v(\{C_1, D_1\})>0$ and the unrestricted Shapley values are

$$(3.12a)\ z_{D_1}^{S} = 1/4 + 1/4v(\{C_1, D_1\}) = z_{C_1}^{S}$$

$$(3.12b)\ z_{D_2}^{S} = 1/4 - 1/4v(\{C_1, D_1\}) = z_{C_2}^{S}$$

since $v(\{C_1, D_1\}) = v(\{C_1, D_1, C_2\}) = v(\{C_1, D_1, D_2\})$. It is obvious that in this subcase the DWFNs as a group are indifferent between restriction and unrestriction. Individually, however, it is more profitable to D_2 to restrict coalition formation than it is to D_1.

Case III

$$(3.13a)\ c_{C_1} < c_{D_1} \le c_{D_2} < c_{C_2}$$

$$(3.13b)\ x_{D_1}^{\infty} \le x_{D_2}^{\infty} < x_{C_2}^{\infty} < x_{C_1}^{*}$$

If $c_{D_1} < c_{D_2} < c_{C_2}$ then the restricted Shapley value is again given by the equal split solution (see equation 2.8). The unrestricted Shapley values are given by

$$(3.14a)\ z_{D_1}^{S} = 1/4 + 1/12v(\{C_1, D_1, D_2\}) + 1/6v(\{C_1, D_1\}) = z_{C_1}^{S}$$

$$(3.14b)\ z_{D_2}^{S} = 1/4 - 1/3v(\{C_1, D_1\}) + 1/12v(\{C_1, D_1, D_2\})$$

$$(3.14c)\ z_{C_2}^{S} = 1/4 - 1/4v(\{C_1, D_1, D_2\})$$

The difference between the sum of restricted and unrestricted Shapley values for the DWFNs is given by

$$(3.15)\ \sum z_{D_i}^{S_R} - \sum z_{D_i}^{S} = -1/12\left[v(\{C_1, D_1, D_2\}) + v(\{C_1, D_1\}) + v(\{C_1, D_1, C_2\})\right] - 1/12\left[v(\{C_1, D_1, D_2\}) - v(\{C_1, D_1\})\right] + v(\{C_1, D_1, C_2\})/4$$

$$= -v(\{C_1, D_1, D_2\})/6 + v(\{C_1, D_1\}) < 0$$

We notice that the DWFNs are worse off in this case because $v(\{C_1, D_1, D_2\}) > v(\{C_1, D_1\})$.

If $c_{D_1} = c_{D_2} < c_{C_2}$ then C_1, D_1 and D_2 are all veto players. Thus, only $v(\{C_1, D_1, D_2\}) > 0$ in the unrestricted situation and the unrestricted Shapley are then given by

$$(3.16a)\ z_{D_1}^{S} = z_{D_2}^{S} = 1/4 + 1/12 v(\{C_1, D_1, D_2\}) = z_{C_1}^{S}$$

$$(3.16b)\ z_{C_2}^{S} = 1/4 - 1/4 v(\{C_1, D_1, D_2\})$$

Comparing the sum of restricted and unrestricted Shapley values for the DWFNs gives

$$(3.17)\ \sum z_{D_i}^{S_R} - \sum z_{D_i}^{S} = -v(\{C_1, D_1, D_2\})/6 < 0$$

Thus, we see that together the DWFNs are again worse off by restricting coalition formation since equation (3.17) is negative.

Furthermore, we should keep in mind that if the roles of the two groups, DWFNs and the coastal states, are changed then opposite results follow. For example, if the DWFNs are both veto players then they are always worse off with restricted coalition formation - an opposite result compared with Case I.

Certainly in Case I for example, there would also be an incentive for the coastal states to bribe one of the DWFNs to join with them. This is true since coastal states loose $v(\{C_1, C_2\})/2 - v(\{C_1, C_2\})/6 = v(\{C_1, C_2\})/3$ due to the restriction, and one DWFN gains simultaneously $v(\{C_1, C_2\})/4 - v(\{C_1, C_2\})/12 = v(\{C_1, C_2\})/6$. Thus the coastal states can afford to offer a bribe worth $v(\{C_1, C_2\})/6$ plus something extra for the other DWFN. However, our model does not involve enough strategic considerations and this analysis is left for further study.

3.2 Increasing the number of players

As was already noted in Section 3.1 the two most efficient members of the regional fisheries organization will always act as veto players in the game, since their presence is necessary for any coalition to obtain a positive bargaining strength. This is due to the ability of the second most efficient nation to harvest the stock down to the non-cooperative level, if necessary. Therefore these veto players will receive an equal share of benefits and the rest of the members receive benefits according to their relative efficiency, but always less than the veto players. Note that there may also be more than two veto players if there are countries that have similar costs of fishing.

In the case of four players, the Shapley values are given by the unrestricted situation of Case I presented in Section 3.1.

Increasing the number of fishing nations to five makes the calculations rather awkward. Indeed, we have 120 different orders of grand coalition formation. Let us assume that

(3.18a) $c_{C_1} < c_{C_2} < c_{D_1} < c_{D_2} < c_{D_3}$

(3.18b) $x^{\infty}_{C_2} < x^{\infty}_{D_1} < x^{\infty}_{D_2} < x^{\infty}_{D_3} < x^{*}_{C_1}$

As noted previously, the veto players C_1 and C_2 are the two most efficient players, and thus their imputations always remain the same. Let us denote this coalition by C for notational convenience. We have

$$(3.19a)\ z_{C_1}^S = z_{C_2}^S = 1/5 + v(\{C\})/20 + \left[\sum_{i=1}^{3} v(\{C, D_i\})\right]/30 + \left[\sum v(\{C, D_{ij}\})\right]/20,$$

where D_{ij} denotes all the possible combinations of DWFNs with two countries.

$$(3.19b)\ \begin{aligned} z_{D_i}^S &= 1/5 - v(\{M \setminus D_i\})/5 + \left[v(\{C, D_i\}) - v(\{C\})\right]/30 \\ &+ \sum \left[v(\{C, D_{ij}\}) - v(\{C, D_j\})\right]/20 \end{aligned}$$

Where $M \setminus D_i$ denotes the grand coalition without D_i. Note that the Shapley imputations for the DWFNs are not equal, and furthermore for the least efficient country D_3, we assume that it does not make any contribution. Thus,

$$(3.19c)\ z_{D_3}^S = 1/5 - v(\{C, D_1, D_2\})/5$$

For six players with the following assumptions

$$(3.20a)\ c_{C_1} < c_{C_2} < c_{D_1} < c_{D_2} < c_{D_3} < c_{D_4}$$

$$(3.20b)\ x_{C_2}^{\infty} < x_{D_1}^{\infty} < x_{D_2}^{\infty} < x_{D_3}^{\infty} < x_{D_4}^{\infty} < x_{C_1}^{*}$$

the Shapley value is given by

$$z^S_{C_1} = z^S_{C_2} = 1/6 + v(\{C\})/30 + \left[\sum_{i=1}^{4} v(\{C, D_i\})\right]/60 + \left[\sum v(\{C, D_{ij}\})\right]/60$$

(3.21a)

$$+\left[\sum v(\{C, D_{ijk}\})\right]/30$$

$$z^S_{D_i} = 1/6 - v(\{M \setminus D_i\})/6 + \left[v(\{C, D_i\}) - v(\{C\})\right]/60$$

(3.21b)

$$+\sum\left[v(\{C, D_{ij}\}) - v(\{C, D_j\})\right]/60 + \sum\left[v(\{C, D_{ijk}\}) - v(\{C, D_j, D_k\})\right]/30$$

And finally for n players with similar assumptions as above

(3.22a) $c_{C_1} < c_{C_2} < c_{D_1} < c_{D_2} < c_{D_3} < c_{D_4} < \ldots < c_{D_n}$

(3.22b) $x^\infty_{C_2} < x^\infty_{D_1} < x^\infty_{D_2} < x^\infty_{D_3} < x^\infty_{D_4} < \ldots < x^\infty_{D_n} < x^*_{C_1}$

we obtain the Shapley imputations for the coastal states as follows

$$z^S_{C_1} = z^S_{C_2} = 1/n + v(\{C\})/(n-1)n + \left[\sum_{i=1}^{n-2} v(\{C, D_i\})\right]/n\binom{n-1}{2}$$

(3.23a) $+\left[\sum v(\{C, D_{ij}\})\right]/n\binom{n-1}{3} + \left[\sum v(\{C, D_{ijk}\})\right]/n\binom{n-1}{4} + \ldots$,

$$+\left[\sum v(\{C, D_{ijk..n-3}\})\right]/n\binom{n-1}{n-2}$$

where $\binom{n-1}{k} = \dfrac{(n-1)!}{k!(n-1-k)!}$.

For the less efficient distant water fishing nations the Shapley imputations are

$$z_{D_i}^S = 1/n - v(\{M \setminus D_i\})/n + \left[v(\{C, D_i\}) - v(\{C\})\right]/n\binom{n-1}{2}$$

$$+\sum\left[v(\{C, D_{ij}\}) - v(\{C, D_j\})\right]/n\binom{n-1}{3}$$

(3.23b)

$$+\sum\left[v(\{C, D_{ijk}\}) - v(\{C, D_j, D_k\})\right]/n\binom{n-1}{4}+\ldots$$

$$+\sum\left[v(\{C, D_{ijk\ldots n-3}\}) - v(\{C, D_j, D_k, \ldots, D_{n-4}\})\right]/n\binom{n-1}{n-2}$$

where subscript ijk...n-3 states that there are n-3 countries for each combination, and D_{n-4} tells us that in this coalition there are n-4 members. For example, with three players C_1, C_2 and D_1 we get the Shapley value by setting n = 3. Similarly, we can check the correspondence to any number of players. With n players, one has to take into account the n-1 first terms from the beginning of equation (3.23), the rest of the terms equal zero or do not exist.

It is clear that the results of Section 3.1 could also be applied to the n-player case. The generalised result would then state that a group of less efficient distant water fishing nations is able to increase their bargaining strength by coalition restrictions. However, as was already seen in the four-player case the results for a given combination of fishing costs might not be very obvious. Therefore we should be careful when drawing conclusions from a given n-player game.

4 DISCUSSION

We have analysed the effects of restricted coalitions in the regional fisheries management organisations setting. We have shown that even the nations with little bargaining power can strengthen their position by joining together and refusing to join with the individually strong countries. However, we have noted that there may be strong incentives for these less efficient nations to cooperate with the stronger fishing nations and thereby receive a larger share of benefits. Thus, more complex modelling of the effects of coalition restrictions are necessary in order to obtain a fuller understanding of how this kind of fisheries management organisations function.

In the current analysis we have not explicitly modeled the strategic behaviour of the countries and therefore further research is needed. Furthermore, we have assumed that the regional fisheries management organisation is formed at stock level x_0, which could most likely be the non-cooperative level of fish stock. However, as the stock starts to increase the bargaining powers of the countries may well change. Another thing that we have not considered here is the issue of endogenous coalition formation. Some promising research of this kind is currently taking place in the field of international environmental agreements.

Furthermore, we have provided with a method to calculate the shares for a large number of members in a regional fisheries management organisation. These results are highly relevant and necessary since there are species like the Northern Atlantic Bluefin Tuna (*Thunnus Thynnus*) for which there are over 20 fishing nations that have serious interest in exploiting the stock and several other nations that might enter the fishery in the future. However, some studies such as Hannesson's (1997) have shown that cooperation might not be sustainable when the number of countries participating in the fishery increases. Thus, further studies are needed to indicate the kind of institutional arrangements which would guarantee cooperation even for such a large number of potential exploiters of straddling and highly migratory fish stocks.

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