A Coalition Game of the Baltic Sea Cod Fishery

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Abstract

The paper sets up a discrete-time, deterministic, coalition game model among the major agents exploiting the cod stock in Baltic Sea. The characteristic function is constructed and the Shapley value and the nucleolus are used as one-point solution concepts. The paper identifies the problem with these sharing rules and develops a new sharing rule which takes into account the stability of cooperation. The paper contributes to the literature by introducing a connection between cooperative games (sharing rules) and non-cooperative games (stability).

Key words: Fisheries, Cooperation, Coalition Game, Baltic Sea Cod, Shapley value, Characteristic function, nucleolus, Sharing rules, stability of cooperation.

JEL Codes: Q22.

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1. Introduction

The Baltic Sea is a sea shared among members of the European Union (EU) (Denmark, Finland, Germany and Sweden) and Estonia, Latvia, Lithuania, Poland and the Russian Federation. The Baltic Sea consists of the central Baltic Sea, the Gulf of Bothnia, the Gulf of Finland, the Sound and the Danish straits. It is a reasonable remote area and it contains no international waters.

The most valuable fishery in the Baltic Sea is the cod fishery which is managed by the International Baltic Sea Fishery Commission (IBSFC). All the parties exploiting the cod stock are members of the IBSFC who sets the total allowable catches (TACs) for the fishery. Seemingly there is a coalition since TAC measures are agreed upon among all contracting parties in the IBSFC. Facts are, however, that TAC measures are often exceeded; free riding on the coalition exists. In 60% of the 15 years with TAC from 1977 to 1998 catches exceed the TACs.[1] In addition to the reported landings it is well known that there exist illegal landings and discards too. Since all countries exploiting the Baltic Sea cod fishery are contracting parties of the IBSFC and the main objective of the fishery commission is 'to cooperate closely' we find it natural to apply a cooperative approach for the analysis. In addition Kronbak & Lindroos (2003) show that coalitions in the Baltic Sea cod fishery should be encouraged. Therefore, in this paper, we apply a characteristic function or a coalition game (c-game) and determine different one-point sharing rules to the Baltic Sea cod fishery.

The c-game approach is based on the fundamental assumption that players have already agreed to cooperate and that the model allows for transferable utility. However, our model endogenises coalition formation and thus searches for equilibrium cooperation structures. Main references in setting up a model of cooperative game of fisheries include Kaitala & Lindroos (1998). They setup a c-game and determine different one-point solution concepts. The model does, however, not take into account the externalities in the fisheries and it is a pure

1 Not in all years there has been a TAC.

theoretical work. Previous empirical work is applying the c-game approach to the Norwegian Spring-spawning Herring (Lindroos & Kaitala (2000) and Arnason, Magnusson & Agnarsson (2000)) and to the Northern Atlantic Bluefin Tuna (Duarte, Brasão & Pintassilgo 2000). These empirical studies do, however, not consider the important connection between the applied sharing rules and the stability of cooperation, therefore none of the determined sharing rules does actually satisfy all players. Brasão, Costa-Duarte & Chunha-e-Sá (2000) applies the c-game to the Northern Atlantic Bluefin Tuna. They recognize the instability of the Shapley value due to free rider incentives; they find a stable non-cooperative feedback Nash with side payments, but are not able to determine the connection between the joint solution and the stability of it.

We contribute to the literature by determining the characteristic function of the Baltic Sea cod fishery and discuss distributions of benefits according to different fair sharing rules. Our main contribution is, however, the development of a new sharing rule which takes into account the stability of cooperation. We also take into account that externalities are present in the fishery, since the strategy chosen inside a coalition also depends on the strategy of the players outside the coalition. There are no international waters in the Baltic Sea, therefore our model does distinguish from previous work, since we can assume there are no potential entrants in the fishery. In addition we also contribute to the literature by allowing all members of a coalition to be active in the fishery until the marginal benefits of the different technologies in the coalition are identical.

Section 2 describes the underlying bio-economic model and applied parameter values. Section 3 solves the game by setting up the c-function and solves for the Shapley value and the nucleolus. It further discusses the stability of the sharing functions and defines a core which is stable to free riding. Section 4 involves a sensitivity analysis and section 5 concludes.

2. The Bio-Economic Model

2.1. Population Dynamics

The population dynamics are described by a discrete time age-structured model. This is a standard type of cohort-model, where the numbers are determined as follows:

$$
\begin{aligned}
&N_{2,y} = R_y && y > y_1 \\
&N_{a+1,y+1} = N_{a,y} e^{-m_a - S_a f_y} && a \in \{2,3,...,7\}, \\
&N_{a,y_1} \ known && a \in \{2,3,...,8\}
\end{aligned}
\tag{1}
$$

where R_y describes the recruitment into the stock at year y, m is the natural mortality, f is the total fishing mortality and S_a is the selectivity of the fishing gear, that if an age class is not harvested, then the selectivity is zero, otherwise one. We assume the initial abundance for all age classes at year y_1, N_{a,y_1}, is known. The population dynamics is determined by 7 age classes, $a=\{2,3,...,8\}$. These age classes are chosen in accordance to the measure by the International Council for the Exploration of the Sea, abbreviated ICES, (ICES 2000) the recruits are aged 2 years before they become a part of the stock. y_1 is the initial year for the simulation model. The biomass is determined as the sum of the number of fish multiplied by their stock weights at age over all age classes:

$$
B_y = \sum_{a=2}^{8} SW_a N_{a,y} , \tag{2}
$$

where SW_a is the stock weights at age and B_y is the biomass in year y. The total spawning stock biomass is given by the sum of mature fish over all age classes:

$$SSB_y = \sum_{a=2}^{8} MO_a SW_a N_{a,y} , \qquad (3)$$

where MO_a is the proportion of fish mature at age class a and SSB_y is the spawning stock biomass in year y. We assume a Beverton-Holt stock-recruitment relationship,j identical to the one used by ICES (2000), defined as follows:

$$R_y = \frac{cSSB_{y-1}}{1 + bSSB_{y-1}} , \qquad (4)$$

where c and b are biological recruitment parameters; c is the maximum recruits per spawner at low spawning stock size and c/b is the maximum number of recruits when the spawning stock biomass is very large.[2] The biological parameters of the stock recruitment relationship and other parameter values are summarized in table 1.

Table 1. Biological parameter values

Parameter	**Value**
Mortality	
$m_{2,3,\ldots,8}$	0.2
Stock-Recruitment (B-H)	
c	0.9814216
b	0.000002340

Source: ICES (2000).

Table 2 identifies the initial biological parameters for the year classes.

2 The stock-recruitment estimated by ICES assumes that recruits are not entering the population before age 2, therefore the SSB is lagged two years in the Beverton-Holt recruitment function applied by ICES (2000). For simplicity reason, we apply only a one-year lag in our simulation model. We do not see this as a critical assumption since the SSB biomass is reasonable monotone on every two successive years.

Table 2. Initial biological parameters

	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8+
MO	0.14	0.32	0.84	0.94	0.98	0.96	1
SW	0.244	0.548	1.230	1.595	2.963	4.624	5.417
CW	0.662	0.773	1.127	1.448	2.337	3.485	4.647
N0	136493	71852	37621	15421	4332	2026	1452

Abbreviations:

MO = Proportion Mature at the Start of the Year

SW = Mean Weight in Stock (kilograms)

CW = Mean Weight in Catch (kilograms)

N0 = Initial Abundance (thousands)

Source: ICES (2000) 1998-estimates.

2.2. The Yield

The catch in numbers for country *i* and for a specific cohort is given by:

$$C_{a,y}^{i} = \frac{S_a f_y^i}{m_a + S_a f_y}\left(N_{a,y} - N_{a+1,y+1}\right), \qquad (5)$$

where f_y^i is the fishing mortality by country *i* and f_y is the total fishing mortality, $C_{a,y}^{i}$ is the catch in number by country *i*, in year *y*, of a specific cohort *a*. The catch function is defined as the numbers of fish that do not surviving to the next year and are not subject to natural mortality.

The yield (harvest) for a single country is defined by inserting the number of fish (1) into the catch in numbers (5) times the catch weights at age:

$$Y_y^i = \sum_{a=2}^{8} CW_a N_{a,y} \frac{S_a f_y^i}{m_a + S_a f_y}\left(1 - e^{-m_a - S_a f_y}\right), \qquad (6)$$

where Y_y^i is the total yield in kg for country i in year y.

2.3. The Cost Function

The cost function is assumed to follow the cost function for harvesting cod in the North Sea for Denmark, Iceland and Norway (Arnason *et al.* 2000):

$$Q_y(t) = \alpha^i \frac{Y_y^{i\,2}}{B_y}, \tag{7}$$

where α^i is a cost parameter and B_y is the total biomass in year y. The dependent variable, costs, is defined as total costs less depreciation, interest payments and skipper wage. This may be regarded as an approximate to total variable costs. The cost function is defined such that if the total biomass is increased the cod are easier to locate and costs are therefore decreased, the effect of other players also exploiting the stock is included in changes in the biomass. It is further important to notice that the costs increase exponentially with the yield. Therefore, in a coalition it is most likely that all countries joining are active, otherwise the coalition is not competitive to countries being singletons.

2.4. The Net Present Value

The net present value is defined as the functional where the control variable is the fishing mortality for player i, f^i, [3] and the state variable is the number of fish in the stock, N, π^i is the instantaneous profit for player i:

$$\pi_y^i = pY_y^i - Q_y^i, \tag{8}$$

3 The way our model is defined, there is a direct link between the fishing mortality and the yield; therefore the control variable might as well be the yield. The fishing mortality would then be determined as a residual.

where π_y^i is the instantaneous profit for country i in year y. The net present value of all future profit for a single player *i* is defined by the functional:

$$J^i\left(f^i, N\right) = \sum_{y=y_1}^{y_2} \frac{\pi_y^i}{\left(1+r\right)^{y_2-y_1}}. \tag{9}$$

The model is assumed to have a finite horizon from y_1 to y_2. We have chosen a period starting from 1997 to 2046, this yields a running period of 50 years. The starting and the ending points of the time horizon are without importance for the model, what matters is the length of the running period.

2.5. Parameter Values

We assume there is an open market for raw fish where the fishermen are all facing the same price for their landings. Furthermore, the Baltic Sea is a comparatively small supplier of cod to a global white fish market in which there are many substitute species and thus the price fishermen are facing is constant. The price which we apply in our model is 10.74 Dkr/kg, this is the average price received on landed cod on the Island of Bornholm in 1998 and 1999 (Fiskeridirektoratet, 1999 and 2000). Bornholm is located relative centrally in the Baltic Sea.

Cost parameters are calibrated for the year 1998. This is done by finding cost parameters which yields a fishing effort and a total biomass population equivalent to the arithmetic mean over the period 1966 to 1999 when fishermen are playing adapting a non-cooperative behaviour. This calibration reveals cost parameters at 9, 14 and 15 Dkr/kg. The cost parameter will be subject for a sensitivity analysis at the end of the paper. We assume there is no technological progress etc. for the simulated 50 years and thus cost parameters and prices remain unchanged throughout the model. So does the functional relationships and there are no stochastic jolts in the system.

We assume country group 1 is the most efficient and country group 3 is the least efficient. We are beforehand able to conclude that, with this type of cost function all countries in a coalition will apply effort until their marginal costs are equivalent. Parameter values for the economic parameters are summarised in table 3.

Table 3. Economic parameter values

Parameter	**Value**
First fishing age, a_1	3
Selectivity S_2	0
Selectivity $S_{3,\ldots,8}$	1
Cost parameter, country 1: α^1	9 Dkr/kg
Cost parameter, country 2: α^2	14 Dkr/kg
Cost parameter, country 3: α^3	15 Dkr/kg
Discount rate, r	2%
Price, p	10.74 Dkr/kg
Max. fishing mortality, $f^1_{\max}$	0.35
Max. fishing mortality, $f^i_{\max}$, i=2,3	0.3

Source: ICES (2000); Fiskeridirektoratet, 1999 and 2000.

We assume a constant fishing mortality over the whole simulation period. Fishermen are committing to their strategies only in the beginning of the game; this is a sort of open loop control. The open loop controls allow the players less rationality and flexibility compared to the closed loop but computing these solutions are a lot easier. There has been a tendency in the literature to resort to the use of open loop solution concepts (Sumaila 1999). The game has complete information (fishermen know all payoff functions) but imperfect information since the fishermen are moving simultaneously.

The following section solves the game by determining the characteristic function and some of the corresponding one-point solution concepts. It further discusses the stability of the sharing rules.

3. Solving the Game

The characteristic function (c-function) is determined and from this function the one-point solution concepts are derived. We apply the definition of the characteristic function described in Mesterton-Gibbons (1992), which are the benefits of cooperation associated with the coalition. That is the difference between the benefits when members form a coalition and the sum of benefits of individual members' e.g. individual players' threat points. We define the characteristic function as follows:

$$\begin{aligned} \bar{v}(i) &= J^i\left(F^i\right) \\ \bar{v}(i,j) &= J^{i,j}\left(F^{i,j}, F^k\right) - \sum_{i,j} J^i\left(F^i\right) \\ \bar{v}(M) &= J^{i,j,k}\left(F^*\right) - \sum_{i=1}^{M} J^i\left(F^i\right), \end{aligned} \tag{10}$$

where $\bar{v}(i)$ is the value of singletons, $\bar{v}(i,j)$ is the value of a two-player coalition and $\bar{v}(M)$ is the value of the grand coalition, that is the maximum payoff by the joint action of all players. F^i is the strategy chosen in Nash equilibrium by coalition i and F^* denotes the full cooperative strategy. J is the functional. The optimal fishing mortalities are determined for all possible coalition structures to determine the characteristic function. We then normalize the function by dividing the characteristic function with the benefits of the grand coalition. The normalized characteristic function, v, has the properties that the value for a grand coalition is 1 and the value for a singleton is zero. We apply a γ-type c-function, where we assume players outside the coalition are adopting Nash-strategies against the coalition (Chander & Tulkens 1997).

When fishermen form a coalition we assume they are rational and therefore distribute effort between participants until the marginal profits of members of the coalition is identical. This distribution yields the highest possible benefits from a coalition. Since we assume fishermen face an identical and constant price on the landed fish, we conclude it is optimal to distribute effort in the coalition such that marginal costs from applying all technologies in the coalition are identical. This requires that a perfect redistribution of effort is possible.[4] The redistribution of effort inside the coalition is a contribution to Lindroos & Kaitala (2000) where it, due to the cost function, is only the most efficient player in the coalition that harvests. Solving the systems such that marginal costs are identical yields constant harvest shares in each year for the members of the coalition, these shares are summarised in table 4.

Table 4. Shares of coalition yield inside the coalition

Coal	**Harvest shares inside coalition**	**Distribution of harvest in coalition with actual costs parameters**
1,2	$\frac{c_2}{c_1+c_2}, \frac{c_1}{c_1+c_2}$	14/23 by tech 1and 9/23 by tech 2
1,3	$\frac{c_3}{c_1+c_3}, \frac{c_1}{c_1+c_3}$	15/24 by tech 1 and 9/24 by tech 3
2,3	$\frac{c_3}{c_2+c_3}, \frac{c_2}{c_2+c_3}$	15/29 by tech 2 and 14/29 by tech 3
1,2,3	$\frac{c_2c_3}{c_1c_2+c_1c_3+c_2c_3}, \frac{c_1c_3}{c_1c_2+c_1c_3+c_2c_3}, \frac{c_1c_2}{c_1c_2+c_1c_3+c_2c_3}$	210/471 by tech 1, 135/471 by tech 2, 126/471 by tech 3

The benefits form the 7 possible coalitions[5] and the optimal strategies are summarised in table 5.

4 Individual transferable quotas (ITQ) might be a possible way to solve that an enormous amount of information is required to distribute effort perfectly.

5 We ignore the empty coalition, in which we assume the benefits are zero.

Table 5. The benefits from the 7 possible coalition structures and the optimal strategies

Coalition	Strategy	Net-Benefit	Free Rider Value
1	0.35	$2.30694 * 10^{10}$	
2	0.29	$1.67376 * 10^{10}$	
3	0.27	$1.56076 * 10^{10}$	
1,2	0.457	$4.25624 * 10^{10}$	$2.02757 * 10^{10}$ (f^3=0.264)
1,3	0.457	$4.12502 * 10^{9}$	$2.10943 * 10^{10}$ (f^2=0.279)
2,3	0.407	$3.35437 * 10^{10}$	$2.84559 * 10^{10}$ (f^1=0.35)
1,2,3	0.351	$7.47167 * 10^{10}$	$6.98259 * 10^{10}$ (Sum of the above)

The benefits from the grand coalition exceed the sum of benefits from free riding, therefore there are enough benefits in the grand coalition to be distributed in a satisfactory way, such that the grand coalition is stable (Pintassilgo 2003). By studying the benefits from the 7 possible coalitions, we clearly see the technological advantage player 1 has, since he receives significant higher benefits than player 2 and 3 both when acting as a singleton and when comparing the free rider values.

The average population of the cod stock in the Eastern Baltic Sea over the period 1966 to 1999 is 500 metric tonnes. Our model suggests a long run population of app. 550 metric tonnes in the non-cooperative scenario and app. 1200 metric tonnes in the cooperative scenario. The population of the cod fishery is at the 1998-level at a very low level, only 174 metric tonnes, therefore each of the scenarios presented starts with a period of rebuilding the population before the long rung equilibrium is reached after app. 10 years. The population of the cod stock when players adapt a cooperative and a non-cooperative behaviour respectively is illustrated in figure 1 and 2.

Figure 1. The population dynamics of full cooperation

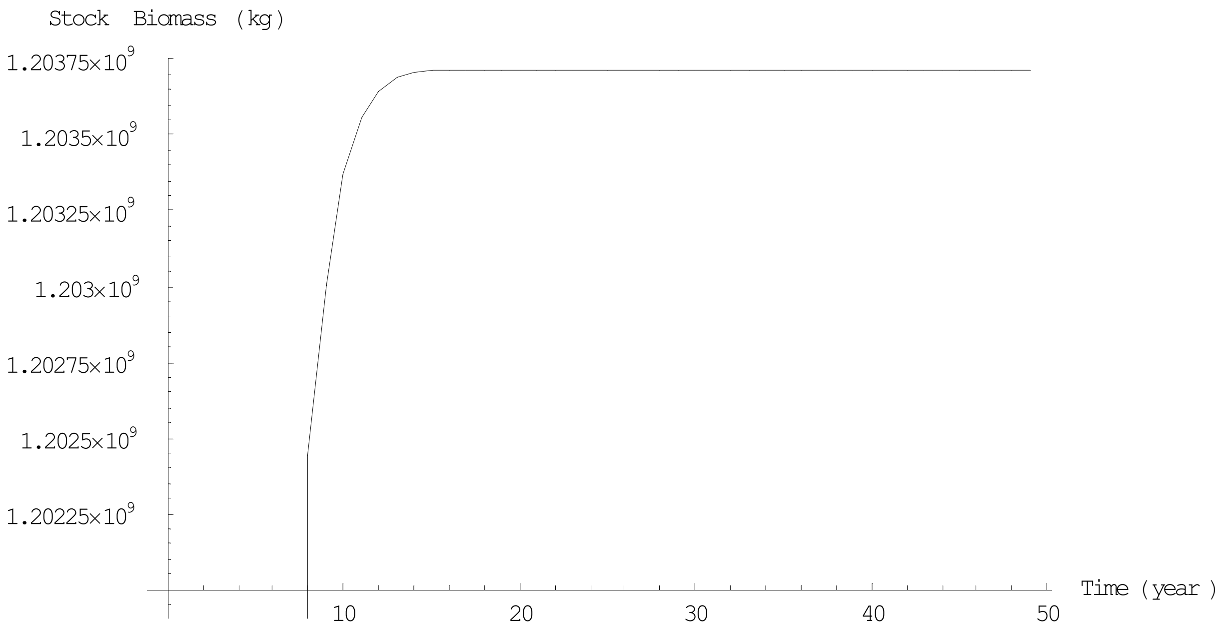
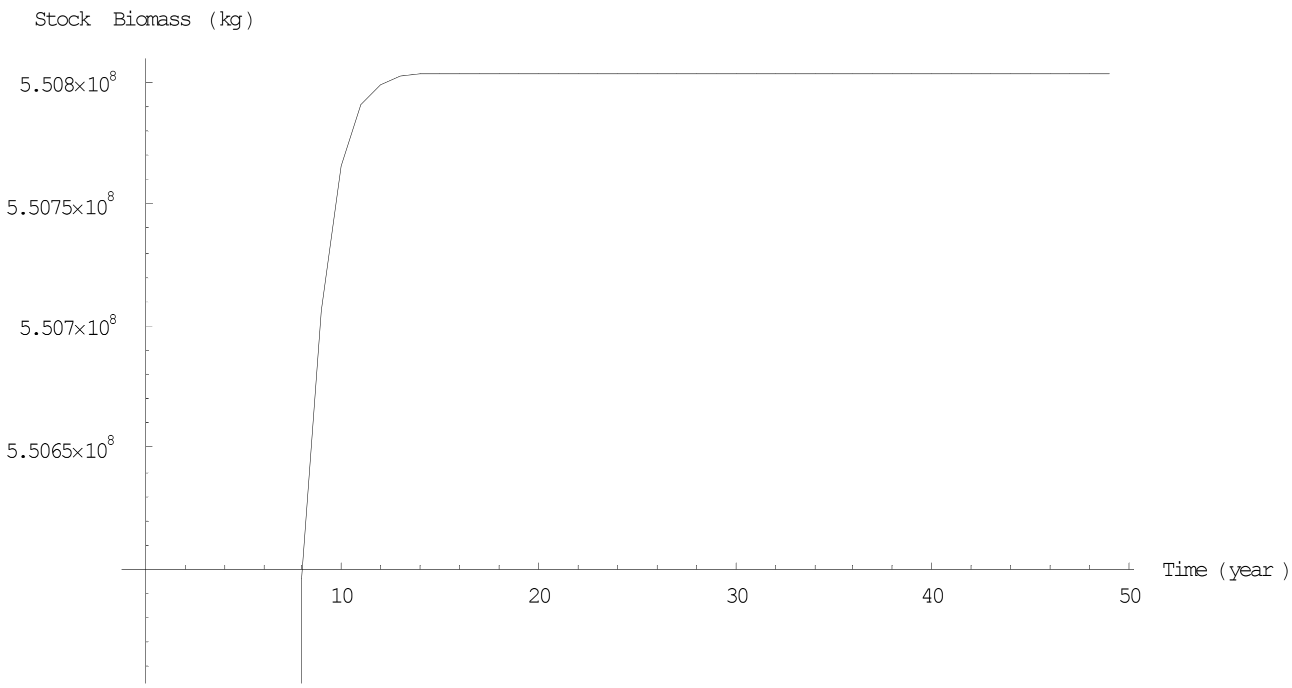


Figure 2. The population dynamics of non-cooperation



In years with high abundance of cod, the population has been at it highest with a population of 1023 metric tonnes.[6] The cooperative equilibrium population might seem unreasonable high compared to the population levels in record, but in neither year the stock has been exploited corresponding to a cooperative behaviour. The non-cooperative simulation has a fishing mortality equivalent of 0.91 and the average fishing mortality from 1966 to 1999 (ICES 2000) has been 0.89. The received total population is within 9 % of the average population estimated by scientist (ICES 2000).

The characteristic function and the normalised characteristic function are determined; the values are illustrated in table 6.

Table 6. The characteristic function & the normalised characteristic function

Coalition	Strategy	Characteristic function	Normalized characteristic function
1	0.35	0	0
2	0.29	0	0
3	0.27	0	0
1,2	0.457	$2.7554*10^9$	0.142751
1,3	0.457	$2.5732*10^9$	0.133312
2,3	0.407	$1.1985*10^9$	0.062092
1,2,3	0.351	$1.93021*10^{10}$	1

From the characteristic function in table 6 it is clearly seen that the two-player coalitions yields relative small benefits compared to the grand coalition. It is also clear that it is relatively important, seen from an economic point of view, to have player 1 joining the coalition.

6 We are considering only the years in record, 1966-1999 (ICES 2000).

Two one-point solutions are applied to determine how the benefits in a cooperative game should be distributed. The two sharing rules are the Shapley value and the nucleolus.

The Shapley value for a single player is defined as the potential to change the worth of the coalition by joining or leaving it, that is the expected marginal contribution. It is determined by the probability of the different coalitions times the marginal contribution to the coalition by player *i*. Applying the characteristic function the Shapley value for player *i* is defined as follows:

$$\phi_i = \frac{\bar{v}(M) - \bar{v}(j,k)}{3} + \frac{\bar{v}(i,j) - \bar{v}(j)}{6} + \frac{\bar{v}(i,k) - \bar{v}(k)}{6} + \frac{\bar{v}(i)}{3}. \qquad (11a)$$

Since we apply a normalised characteristic function the Shapley value becomes:

$$\phi_i = \frac{1 - v(j,k)}{3} + \frac{v(i,j)}{6} + \frac{v(i,k)}{6}. \qquad (11b)$$

Equations (11a) and (11b) describe player *i*'s expected marginal contribution.

The idea of the nucleolus is to minimize the dissatisfaction of the coalition. This is done by finding the 'lexicographic center' of the core, which is the imputation maximizing the minimum gains to any possible coalition. The nucleolus has the advantage that it always lies in the core, if it exits. To determine the nucleolus, we define the reasonable set, the excess function and the core.

The reasonable set is defined as imputations satisfying three equations; First, a player receives no more than what he contributes to the coalition. Second, the imputation is individually rational, that is all players should be better of with cooperation. Third, the imputation is Pareto-optimal or group rational, that is, all benefits are distributed among players. The reasonable set determines the set of fair distributions of the benefits.

The excess is defined as the difference between the fraction of the benefits of cooperation that S can obtain for itself and the fraction of benefits of cooperation that the imputation allocates to S.

$$e(S,x) = v(S) - \sum_{i \in S} x_i \, , \tag{12}$$

where $x=(x_1,x_2,x_3)$ is a three dimensional vector describing different shares (imputations), and x_i describes the share to player i. The core is defined by the excess being negative as an addition to the reasonable set, thus the core in our case looks like follows:

$$\begin{aligned} &0.142751 - x_1 - x_2 \le 0 \\ &0.133312 - x_1 - x_3 = 0.133312 - x_1 - (1 - x_1 - x_1) = x_2 - 0.866688 \le 0 \, . \\ &0.062092 - x_2 - x_3 = 0.062092 - x_2 - (1 - x_1 - x_2) = x_1 - 0.937908 \le 0 \end{aligned} \tag{13}$$

In this specific case, the core does not narrow down number of imputations since the core and the reasonable set coincide. The reason for this is that the contribution from all three players to the grand coalition is relatively high, or said in another way the two-player coalitions have relatively low payoffs. Thus, the gains from a grand coalition are significantly higher than the gain from a two-player coalition. The benefits from the coalitions are connected with the externalities. In a two-player coalition the players inside and outside the coalition are playing a Nash game against each other, thus externalities are present. Moving from a two-player coalition to the grand coalition the externalities then disappear since all players are joining together and acting as a sole owner.

The rational ε-core is determined by shrinking the boundaries of the core with the same rate until it collapses into either a line or a single point. This defines the least rational ε-core. In our case this corresponds to a lower bound of ε which is -0.3333, setting ε to this lower bound yields the following equations:

$$0.3333 \le x_1 \le 0.604475$$
$$0.3333 \le x_2 \le 0.533355. \quad (14)$$
$$0.476084 \le x_1 + x_2 \le 0.66667$$

Clearly, the only imputation satisfying these equations is x_1=x_2=x_3=0.333, which is the least rational core. Since the boundary of the core collapses to a single point, this is identical to the nucleolus.

The Shapley value is determined from equation (11b), and after determining the value we easily confirm that in our case the Shapley values lie within the core. Table 7 summarises the imputations determined by the two one-point solution concepts.

Table 7. Sharing functions[7]

Player	Shapley	Nucleolus
1	0.359	0.333
2	0.323	0.333
3	0.318	0.333

The reason for the nucleolus to distribute benefits equally among the players is that none of the two-player coalitions has a very high value determined by the normalised characteristic function. Thus, the boundaries of the reasonable set which is identical to the core in this case are determined mainly by the individual rationality and the centre of this set then becomes an equal share to the players. The Shapley value is based on the average contribution to the coalition of the players by joining or leaving it and since player 1 has the lowest cost parameter it contributes on average more to the coalitions than the other players, therefore the Shapley value for player 1 exceeds the Shapley value of other players. The results from the game in table 7 clearly illustrate the difference between the two one-point solution concepts. Both results are in the core and are

7 Rounding of numbers may cause that the sharing imputations do not sum to one.

characterised as fair sharing rules. There is, however, still a problem since player 1 is not satisfied with the nucleolus sharing rule. With the nucleolus sharing rule, player 1 receives 33.3% of the cooperative benefits but by free riding on the grand coalition player 1 can receive what corresponds to 38.1% of the cooperative benefits. Player 1 is clearly better of by free riding. Therefore, the grand coalition applying this nucleolus sharing rule is not a stable cooperative solution. It is further noticed that neither the Shapley value with 35.9% of the cooperative benefits does satisfy player 1 compared to his free rider value.

The Baltic Sea does, at the moment, not face a cooperative harvest solution for the cod fishery. This can be explained as instability by our model if the benefits in a cooperative solution are distributed according to the Shapley or the nucleolus sharing rules. Some players do have an incitement to free ride and the cooperative agreement collapses. The problem is that the sharing rules do not take the stability of cooperation into consideration. This is a problem which also occurs in previous empirical studies (Lindroos & Kaitala (2000), Arnason, Magnusson & Agnarsson (2000)) Duarte, Brasão & Pintassilgo (2000)) but is not recognized.[8] Brasão, Duarte & Cunha-e-Sá (2000) do identify the problem but do not suggest a cooperative solution to it.

We therefore suggest another distribution, than previously applied in the literature, of the cooperative benefits solution concept. We define a new set, namely *the satisfactory core*. This is done by redefining the core by applying the concept *individual satisfaction*. The *individual satisfaction* ensures players are at least as good of as when free riding, this is a parallel to the individual rationality which ensures the players are as good of as when playing singletons. The breaking point is that players have already agreed to cooperate and if they should stick to this agreement, they must not be tempted to deviate, hence the

8 One could argue that free riding on the grand coalition is short-sighted since the grand coalition then most likely would break down in the long run. If this is the case, then the stability should be discussed in the light of Trigger strategies. We prefer, instead, to search for a distribution of benefits among members, which is also stable compared to free rider value.

sharing rule should ensure all players receives at least their free rider value. Let us define the *satisfactory core* as follows:

$$e(S,x) = v(S) - \sum_{i \in S} x_i \leq 0$$
$$x_i \geq \frac{v(freerider)}{v(M)} \text{ } (\textit{Individual Satisfaction}). \qquad (15)$$
$$x_1 + x_2 + x_3 = 1$$

The satisfactory core deviates from the ordinary core by the individual satisfaction. In our specific case the individual satisfaction is determined as follows:

$$x_1 \geq 0.3809$$
$$x_2 \geq 0.2823 . \qquad (16)$$
$$1 - x_1 - x_2 \geq 0.2714$$

Comparing the sharing rules from table 7 we clearly see, that both the Shapley value and the nucleolus violates the individual satisfaction for player 1.

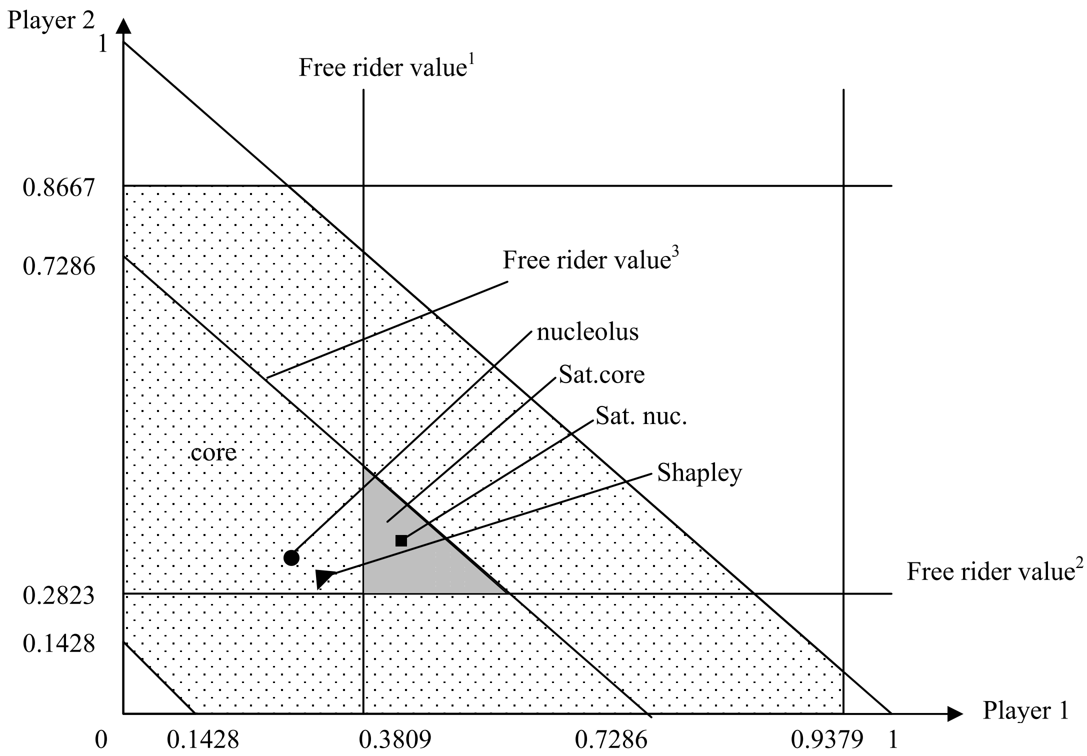
We define another sharing rule, the *satisfactory nucleolus*, which is similar to the nucleolus in the sense that it is defined as the lexicographic center of the satisfactory ε-core. The results of the satisfactory nucleolus is summarised in table 8.

Table 8. Satisfactory nucleolus

Player	**Satisfactory nucleolus**
1	0.4027
2	0.3041
3	0.2932

A graphic illustration of the difference between the core and the satisfactory core and the three applied sharing rules is available in figure 3.

Figure 3. The reasonable set, the core and the satisfactory core. The sharing rules; the nucleolus, the Shapley value and the satisfactory nucleolus



The satisfactory nucleolus is a cooperative sharing imputation which is stable to free rider values, since it is defined with the aim to take the stability into account. The satisfactory nucleolus does therefore recognize the connection between non-cooperative and cooperative games. The satisfactory nucleolus takes into account that player one has relative large gains by free riding on the grand coalition, therefore he receives a larger share of the cooperative benefits compared to the other two players. Our model suggests the satisfactory nucleolus as a sharing rule to be administered by the IBFSC for reaching a stable cooperative solution in the Baltic Sea cod fishery.

4. Sensitivity Analysis

The robustness of the results has been tested by varying the different economic and biological parameters. The results of the sensitivity analysis are included in the appendix.

In particular we have focused on economic parameters as the cost parameters, the discount rate and simulation length. Cost parameters have been increased, decreased and their mutual proportions have been changed, we have tested another 6 different sets of cost parameters. None of these changes affects that a stable grand coalition is a possible stable solution. The cost parameters mutual proportions and their level do, however, have an effect on the stability of the different sharing rules. If the cost parameters are all very low, then the players and the partial coalitions will apply full effort and the free rider values coincide with the singleton benefits. The core and the satisfactory core are identical and both Shapley and nucleolus are located in the core and are therefore stable sharing rules. Also, if countries have relatively identical cost parameters then they receive relatively equal benefits by free riding which makes it more likely that the existing sharing rules are also located in the satisfactory core. If, however, one country is relatively more efficient compared to the others, then he receives relatively large benefits from free riding which can diminish the satisfactory core significantly, making it more unlikely that the Shapley value and the nucleolus are stable sharing rules. Increasing the discount rate to 5% and 8%, respectively, does neither change the fact that it is possible to find a stable cooperative solution; the Shapley value and the nucleolus are, however, unstable. Reducing the simulation length from 50 years to 25 years also shows that it is possible to find a stable cooperative solution, but again we have to search among other solutions than the Shapley value and the nucleolus to reach stability.

The Beverton-Holt stock-recruitment curve has been shifted up and down by increasing and decreasing the maximum recruits per spawner at low spawning stock size (the parameter c in equation (4)). It remains possible to find a stable cooperative solution, but the Shapley values and the nucleoli are again not among these stable solutions.

The initial conditions which include the initial abundance of cod, the stock weight at age, the catch weight at age and the proportion of the stock which is mature is changed (these initial conditions refers to table 2). The original scenario is based on data from the 1998-level, which is a year, together with the other more recent years, with a low abundance of cod. The initial level has therefore for the purpose of sensitivity been set to the 1982-level, which is the year in record with the highest abundance of cod (ICES 2000). These simulations do, however, show the same trend as the other results. There exists a stable grand coalition, but not the Shapley value, neither the nucleolus are stable solutions.

We can thus conclude the grand coalition formed by our model is a rather robust solution since we can find a stable sharing rule in all the analysed cases, whether the Shapley values and the nucleoli are among these sharing rules are more parameter specific.

5. Conclusion

Our model shows that there are enough benefits to make all players better off in the grand coalition compared to non-cooperative or partly cooperative solution. This result is in stark contrast with the previous more pessimistic empirical c-game models. The critical point is how the benefits received in a grand coalition are shared among the players in the game. Two different known one-point sharing rules, the Shapley value and the nucleolus are not taking the stability of the collation into account even though they are both located in the core and are both characterised as fair sharing rules. If the benefits in the Baltic Sea cod fishery are shared according to these rules it is shown to be an unstable solution which does not satisfy all players of the grand coalition since one player is better of by free riding. We therefore suggest another sharing rule connection the cooperative and the non-cooperative game. The satisfactory core takes into account the stability of the grand coalition, by including the free rider values as threat points. The corresponding satisfactory nucleolus sharing rule ensures all players receive a share of the cooperative benefits which is at least at large as their free rider value, this yields a stable sharing imputation. A cooperative solution can be stable, but the Achilles heal is the distribution of the benefits and one should be aware that all players are satisfied compared to their cooperative benefits. If the satisfactory nucleolus sharing rule is applied to the Baltic Sea cod fishery we show that a stable solution can be achieved.

Our model is limited to three players, argued by the fact that in some countries fishermen are members of producer organizations (POs) and these organizations acts as a single group. This assumption might be critical because not all countries have a high degree of memberships of POs. If the number of players in a c-game increases, it most likely becomes more difficult to achieve a grand coalition solution. Olson (1965) discusses this as a general problem to collective goods, and Hannesson (1997) discusses it as a problem in fishery models, where he defines the critical number of fishermen for a full cooperative solution. A reason for not having a grand coalition in the Baltic Sea fisheries might be, that having all fishermen joining a grand coalition yield high transaction cost of planning and organising the grand coalition but also decreases the likelihood of a stable grand coalition. The organizing of a grand coalition should be done in already existing commissions such as the IBSFC and a solution to the redistribution problem might be to introduce individual transferable quotas (ITQ). The number of players could be reduced by supporting memberships of POs and support organising POs in developing countries.

Our model is stable to changes in both economic and biological parameter values and for many of the tested scenarios the pattern is the same, namely that the nucleoli and the Shapley values are not stable solutions. This conclusion can also be drawn from the previous literature (Lindroos & Kaitala (2000), Arnason, Magnusson & Agnarsson (2000)) Duarte, Brasão & Pintassilgo (2000)) and we therefore find it particularly important to recognize the connection between the sharing rule and the free rider values, which is done in the development of the satisfactory nucleolus.

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7. Appendix Sensitivity Analysis

This appendix summarizes the results of the simulations which are calculated for the sensitivity analysis.

Table A.1. Cost parameters decreased α_1=3, α_2=4 and α_3=5

Coal	f	Benefits	Free Rider	Population
1	0.3	$2.61694*10^{10}$		
2	0.3	$2.53503*10^{10}$		$5.56*10^{8}$
3	0.3	$2.45311*10^{10}$		
1,2	0.6	$5.16367*10^{10}$	0.3 $2.45311*10^{10}$	$5.56*10^{8}$
1,3	0.6	$4.9965*10^{10}$	0.3 $2.61694*10^{10}$	$5.56*10^{8}$
2,3	0.6	$5.10349*10^{10}$	0.3 $2.53503*10^{10}$	$5.56*10^{8}$
1,2,3	0.444	$8.32922*10^{10}$	7.60508 (Sum of above)	$11.01*10^{8}$

The corresponding sharing rules and the minimum values in satisfactory core.

Player	Shapley	Nucleolus	Min. value sat. core
1	0.3399	0.3333	0.3142
2	0.3226	0.3333	0.3044
3	0.3376	0.3333	0.2945

Both the Shapley value and the nucleolus are above the minimum value of the satisfactory core.

Table A.2. Cost parameters increased α_1=10, α_2=20 and α_3=25

Coal	f	Benefits	Free Rider	Population
1	0.3	$2.7587*10^{10}$		
2	0.21	$1.63663*10^{10}$		$6.93*10^{8}$
3	0.18	$1.33973*10^{10}$		
1,2	0.381	$4.65462*10^{10}$	0.177 $1.68804*10^{10}$	
1,3	0.376	$4.27453*10^{10}$	0.21 $1.96356*10^{10}$	
2,3	0.302	$3.01296*10^{10}$	0.3 $3.20124*10^{10}$	
1,2,3	0.335	$7.13901*10^{10}$	6.85284 (Sum of above)	$12.4*10^{8}$

The corresponding sharing rules and the minimum values in satisfactory core.

Player	Shapley	Nucleolus	Min. value sat. core
1	0.376	0.3333	0.448
2	0.327	0.3333	0.27
3	0.297	0.3333	0.23

Neither the Shapley value nor the nucleolus is located inside the minimum satisfactory core.

Table A.3. Cost parameter 1 is increased, while cost parameters 2 and 3 are decreased α_1=11, α_2=12 and α_3=13

Coal	f	Benefits	Free Rider	Population
1	0.3	1.96161*1010		
2	0.3	1.87969*1010		5.56*108
3	0.3	1.79778*1010		
1,2	0.6	4.00908*1010	0.294 2.19528*1010	
1,3	0.6	3.92289*1010	0.3 2.30837*1010	5.56*108
2,3	0.6	3.86491*1010	0.3 2.46062*1010	5.56*108
1,2,3	0.444	7.48032*1010	6.96427 (Sum of above)	11.6*108

The corresponding sharing rules and the minimum value in satisfactory core.

Player	Shapley	Nucleolus	Min. value sat. core
1	0.3294	0.3333	0.3289
2	0.3359	0.3333	0.3086
3	0.3347	0.3333	0.2935

The Shapley value is located inside the satisfactory core, while the nucleolus is located outside the satisfactory core.

Table A.4. Cost parameter 1 is decreased, while cost parameters 2 and 3 are unchanged α_1=7, α_2=14 and α_3=15

Coal	f	Benefits	Free Rider	Population
1	0.3	$2.40882*10^{10}$		
2	0.29	$1.78852*10^{10}$		$5.76*10^{8}$
3	0.27	$1.66774*10^{10}$		
1,2	0.5	$4.4372*10^{10}$	0.267 $1.89725*10^{10}$	
1,3	0.5	$4.3137*10^{10}$	0.282 $1.97318*10^{10}$	
2,3	0.378	$3.55216*10^{10}$	0.3 $3.13347*10^{10}$	
1,2,3	0.38	$7.59993*10^{10}$	7.0039 (Sum of above)	$11.4*10^{8}$

The corresponding sharing rules and the minimum value in satisfactory core.

Player	Shapley	Nucleolus	Min. value sat. core
1	0.361	0.3333	0.412
2	0.320	0.3333	0.260
3	0.319	0.3333	0.250

Neither the Shapley value nor the nucleolus is located inside the minimum satisfactory core.

Table A.5. Cost parameter 1, 2 and 3 are increased α_1=10, α_2=17 and α_3=20

Coal	f	Benefits	Free Rider		Population
1	0.3	$2.47623*10^{10}$			
2	0.24	$1.70434*10^{10}$			$6.38*10^{8}$
3	0.22	$1.48717*10^{10}$			
1,2	0.405	$4.46064*10^{10}$	0.21	$1.86232*10^{10}$	
1,3	0.398	$4.17531*10^{10}$	0.237	$2.07959*10^{10}$	
2,3	0.341	$3.30046*10^{10}$	0.3	$2.99135*10^{10}$	
1,2,3	0.351	$7.26235*10^{10}$	6.93326 (Sum of above)		$12.0*10^{8}$

The corresponding sharing rules and the minimum value in satisfactory core.

Player	Shapley	Nucleolus	Min. value sat. core
1	0.362	0.3333	0.412
2	0.330	0.3333	0.286
3	0.308	0.3333	0.256

Neither the Shapley value nor the nucleolus is located inside the minimum satisfactory core.

Table A.6. Cost parameter 1, 2 and 3 are decreased α_1=3, α_2=9 and α_3=10

Coal	f	Benefits	Free Rider	Population
1	0.3	$2.61694*10^{10}$		
2	0.3	$2.12544*10^{10}$		$5.56*10^{8}$
3	0.3	$2.04353*10^{10}$		
1,2	0.6	$4.98814*10^{10}$	0.3 $2.04353*10^{10}$	
1,3	0.6	$4.96766*10^{10}$	0.3 $2.12544*10^{10}$	
2,3	0.463	$3.98525*10^{10}$	0.3 $3.13517*10^{10}$	
1,2,3	0.441	$8.13733*10^{10}$	7.30414 (Sum of above)	$10.1*10^{8}$

The corresponding sharing rules and the minimum value in satisfactory core.

Player	Shapley	Nucleolus	Min. value sat. core
1	0.4468	0.3333	0.3853
2	0.2652	0.3333	0.2612
3	0.2874	0.3333	0.2511

The Shapley value is located inside the satisfactory core, while the nucleolus is located outside the satisfactory core.

Table A.7. The simulation length is reduced from 50 years to 25 years

Coal	f	Benefits	Free Rider	Population
1	0.35	$1.30736*10^{10}$		
2	0.28	$0.92641*10^{10}$		$5.57*10^{8}$
3	0.27	$0.877515*10^{10}$		
1,2	0.458	$2.3929*10^{10}$	0.258 $1.11321*10^{10}$	
1,3	0.457	$2.31952*10^{10}$	0.273 $1.16183*10^{10}$	
2,3	0.4	$1.8647*10^{10}$	0.35 $1.59656*10^{10}$	
1,2,3	0.36	$4.09643*10^{10}$	3.8716 (Sum of above)	$12.0*10^{8}$

The corresponding sharing rules and the minimum value in satisfactory core.

Player	Shapley	Nucleolus	Min. value sat. core
1	0.3625	0.3333	0.3897
2	0.3250	0.3333	0.2836
3	0.3126	0.3333	0.2718

Neither the Shapley value nor the nucleolus is located inside the minimum satisfactory core.

Table A.8. The discount rate is increased from 2% to 5%

Coal	f	Benefits	Free Rider	Population
1	0.35	$1.34334*10^{10}$		
2	0.28	$0.956889*10^{10}$		$5.56*10^{8}$
3	0.27	$0.90354*10^{10}$		
1,2	0.457	$2.4498*10^{10}$	0.261 $1.15031*10^{10}$	
1,3	0.457	$2.38874*10^{10}$	0.272 $1.19636*10^{10}$	
2,3	0.408	$1.91882*10^{10}$	0.35 $1.62435*10^{10}$	
1,2,3	0.36	$4.22777*10^{10}$	3.97102 (Sum of above)	$11.8*10^{8}$

The corresponding sharing rules and the minimum value in satisfactory core.

Player	Shapley	Nucleolus	Min. value sat. core
1	0.3618	0.3333	0.3842
2	0.3210	0.3333	0.2830
3	0.3172	0.3333	0.2721

Neither the Shapley value nor the nucleolus is located inside the minimum satisfactory core.

Table A.9. The discount rate is increased from 2% to 8%

Coal	f	Benefits	Free Rider	Population
1	0.35	$0.878044*10^{10}$		
2	0.28	$0.621941*10^{10}$		$5.56*10^8$
3	0.27	$0.586624*10^{10}$		
1,2	0.466	$1.60152*10^{10}$	0.258 $0.73112*10^{10}$	
1,3	0.459	$1.56177*10^{10}$	0.269 $0.77828*10^{10}$	
2,3	0.407	$1.24697*10^{10}$	0.35 $1.05634*10^{10}$	
1,2,3	0.369	$2.71421*10^{10}$	2.56574 (Sum of above)	$11.6*10^8$

The corresponding sharing rules and the minimum value in satisfactory core.

Player	Shapley	Nucleolus	Min. value sat. core
1	0.3657	0.3333	0.3892
2	0.3189	0.3333	0.2867
3	0.3154	0.3333	0.2694

Neither the Shapley value nor the nucleolus is located inside the minimum satisfactory core.

Table A.10. The a parameter in the BH stock-recruitment is increased by 10%; c'=c*1.1

Coal	**f**	**Benefits**	**Free Rider**	**Population**
1	0.35	$2.52597*10^{10}$		
2	0.29	$1.8308*10^{10}$		$6.06*10^{8}$
3	0.27	$1.70722*10^{10}$		
1,2	0.459	$4.66369*10^{10}$	0.264 $2.21184*10^{10}$	
1,3	0.45	$4.51287*10^{10}$	0.28 $2.33382*10^{10}$	
2,3	0.4	$3.67365*10^{10}$	0.35 $3.14921*10^{10}$	
1,2,3	0.351	$8.19474*10^{10}$	7.69487 (Sum of above)	$13.2*10^{8}$

The corresponding sharing rules and the minimum value in satisfactory core.

Player	**Shapley**	**Nucleolus**	**Min. value sat. core**
1	0.3580	0.3333	0.3843
2	0.3242	0.3333	0.2848
3	0.3178	0.3333	0.2700

Neither the Shapley value nor the nucleolus is located inside the minimum satisfactory core.

Table A.11. The a parameter in the BH stock-recruitment is decreased by 10%; c''=c*0.9

Coal	f	Benefits	Free Rider	Population
1	0.35	$2.08737*10^{10}$		
2	0.29	$1.51614*10^{10}$		$4.96*10^{8}$
3	0.27	$1.41376*10^{10}$		
1,2	0.458	$3.83037*10^{10}$	0.267 $1.83281*10^{10}$	
1,3	0.457	$3.72963*10^{10}$	0.279 $1.90973*10^{10}$	
2,3	0.405	$3.03414*10^{10}$	0.35 $2.58192*10^{10}$	
1,2,3	0.351	$6.74812*10^{10}$	6.32446 (Sum of above)	$10.8*10^{8}$

The corresponding sharing rules and the minimum value in satisfactory core.

Player	Shapley	Nucleolus	Min. value sat. core
1	0.3571	0.3333	0.3826
2	0.3212	0.3333	0.2830
3	0.3217	0.3333	0.2716

Neither the Shapley value nor the nucleolus is located inside the minimum satisfactory core.

Table A.12. The initial biological parameters are changed to the 1982 which represents the year in record with the highest abundance of cod

Coal	**f**	**Benefits**	**Free Rider**	**Population**
1	0.35	$2.24885*10^{10}$		
2	0.3	$1.72963*10^{10}$		$5.012*10^{8}$
3	0.3	$1.67307*10^{10}$		
1,2	0.58	$4.02556*10^{10}$	0.3 $1.80775*10^{10}$	
1,3	0.57	$3.9908*10^{10}$	0.3 $1.89388*10^{10}$	
2,3	0.5	$3.39684*10^{10}$	0.35 $2.52569*10^{10}$	
1,2,3	0.387	$6.94626*10^{10}$	6.22732 (Sum of above)	$9.83*10^{8}$

The corresponding sharing rules and the minimum value in satisfactory core.

Player	**Shapley**	**Nucleolus**	**Min. value sat. core**
1	0.3498	0.3333	0.3636
2	0.3201	0.3333	0.2726
3	0.3293	0.3333	0.2602

Neither the Shapley value nor the nucleolus is located inside the minimum satisfactory core.

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