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Allocation and sharing in international fisheries agreements

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1. Introduction

Many fish stocks migrate in the seas and thus disregard completely economic boundaries. The exclusive economic zones (EEZs) define the economic boundaries and are the basis on which the ownership to the seas are allocated. This creates a complexity in the management of such fisheries. This complexity implies that several nations exploit common stocks which create strategic interaction in-between nations, since one nation's action affects the availability of the fish stock and thus the economic outcome of other nations. To cope with this type of problems game theory provides a tool box to analyze the offset. This paper opens part of the toolbox to provide the reader with understanding of how allocation and sharing of benefits can be done in international fisheries agreements. Game theory is a tool which can help provide explanations for the different behaviors in fishery and can help defining the allocation and sharing of benefits which have to be changed to reach more preferable outcomes. For an introduction on the application of game theory to fishery economics, see Kronbak and Lindroos (2010).

In its nature the cooperative or the joint outcome of management of shared resources provides a first best solution. The cooperative outcome of a game is maximizing the benefits of joint action. Therefore organizations like the European Union (EU), the Regional Advisory Councils (RACs) and other regional fisheries management organisations (RFMOs) aim at making agents cooperate closely, since this is the economic efficient outcome from the fishery. The problem in such joint agreements is the incentives to free ride. A free rider is an agent leaping out of the agreement and benefit from others jointly reducing their effort. The incentives to free ride are strengthened because of external effects in fisheries. Applying the game theoretic tools to models, simulating real world fisheries, can help finding explanations for the actual behaviour of fishermen and can help define the settings under which a cooperative solution can be stable. Munro (1979) emphasised the issue of side payments as a possibility for facilitating the resource conflict, demonstrated in a two player game. Having more players exploiting a common resource complicates matters and side-payments have to be systematised. The reaming question is, therefore, to find a reasonable way for dividing the benefits among more players to ensure internal stability for the agreed exploitation pattern. This is also highlighted in Bloch (2003) who formulates three basic questions of endogenous coalition formation: 1) Which coalitions will form? 2) How will the coalitional worth be divided among coalition members? 3) How does the presence of other coalitions affect the incentives to cooperate? The allocation and sharing of benefits in international fisheries agreements focuses on question 2), on how the coalition worth is divided among coalition members. It implicitly assumes that the grand coalition is the offset for the allocation sharing (question 1) (for an over view of coalition formation in fisheries see Lindroos *et al*., 2007) and in many cases apply the formulation of alternative coalitions or free riders as threat point for joint outcome (question 3). This paper has a primary focus the second question formulated by Bloch (2003) namely how to share joint benefits avoiding free rider incentives in a joint agreement.

The paper starts out by describing the cooperative games and coalition formation. It then discusses the allocation and sharing of joint benefits which is the core section of the paper. It continues by highlighting problems that relates to the before discussed allocation principles. The final section concludes the paper. Thorough out the paper the same numerical example is applied for illustrative purpose.

2. Modelling the allocation and sharing in international fisheries agreements

International fisheries include several countries harvesting a common fish stock. It is well-known in the literature that economically efficient use of these resources requires that the countries are able to sign and ratify an agreement governing the exploitation of the stock, thus engaging in a cooperative exploitation of the resource. In the case it is assumed that the agreement is binding for all countries involved the relevant modelling tools are found within cooperative game theory.

In cooperative games the countries are maximising their joint net benefits from the fishery (or fisheries). This means that they will sum up all revenues and all costs for all countries from a given period of time. In addition, a discount rate is used to compute the sum of net benefits in today's money. Therefore, it ends up in a sum of NPV's of the countries, where NPV stands for the net present value of the fishery. Mathematically this can be formulated as follows for *n* countries with effort levels corresponding to E_i for country *i*:

$$\max_{E_1,\dots,E_n} NPV = \sum_{i=1}^{n} NPV_i(E_1, \dots, E_n)$$

Further issues in cooperative games include the analysis of coalitions, where not all nations but only some formulates an agreement on sharing of benefits and stability.

In cooperative games the countries can negotiate an agreement with other countries individually or together with other countries. This means that cooperative games take into account all possible coalitions countries can form with one another. If they negotiate alone they are called singletons. If they all negotiate together they are called the grand coalition and any negotiations in between these are called a coalition. All coalitions, including the singletons and the grand coalition, will maximise the sum of net present values of its members (Lindroos *et al.* 2007). From a theoretical perspective this assumes the most efficient technologies available in the coalition are applied as much a possible, but in real world setting it might refer to efficiency without optimality since there might be political constraints on all coalition members being active in a fishery.

Traditionally the games in fishery economics are solved by the characteristic function game, which assumes that all players cooperate and any coalitions smaller than the full cooperation defines threat point for what would have been possible in the case of deviation from the grand coalition. The characteristic function is then defined as the difference between the benefits when members form a coalition (defined as NPV(S)) and the sum of benefits of individual members (defined as NPV(({i}), the benefits to the singleton {i}). This function assigns a value to each coalition and is defined as a function of the size of the coalition $\bar{v}(S)$, where $S \subseteq N$, and *N* is the grand coalition.

$$\bar{v}(S) = NPV(S) - \sum_{i \in S} NPV(\{i\})$$

For all $\subseteq N$.

The following introduces a numerical example, which will be applied throughout the paper for illustrative purpose. It is an example with three player or fishing nations. Imagine that the Net Present Values of the coalitions are (in millions USD) NPV{1}=1, NPV {2}=2, NPV {3}=3, NPV {1,2}=4, NPV {1,3}=5, NPV {2,3}=6, NPV {1,2,3}=10 and that these values are calculated based on a bio-economic model. The c-function and the normalised c-function (normalisation towards the joint benefits) are summarised in the following Table1.

Table 1

The c-function (values in millions USD) and

the normalised c-function (measured in fractions of joint benefits).

c-function, $\bar{v}(S)$	Normalised c-function, $v(S) = \frac{\bar{v}(S)}{\bar{v}(N)}$
$\bar{v}$({1})=0	v({1})=0
$\bar{v}$({2})=0	v({2})=0
$\bar{v}$({3})=0	v({3})=0
$\bar{v}$({1,2})=1	v({1,2})=1/4
$\bar{v}$({1,3})=1	v({1,3})=1/4
$\bar{v}$({2,3})=1	v({2,3})=1/4
$\bar{v}$({1,2,3})=4	v({1,2,3})=1

Note: $S \subseteq N$, where S is a coalition and N is the grand coalition

In the normalised c-function the normalised towards the grand coalition ensures the value of the grand coalition is normalised to 1. The game is superadditive, since the normalised c-function is positive.

Including the free-rider values to the normalised c-function would create a partition function, p-function, which thus includes values to the coalition, but also to the nations outside the coalition. The p-function for the example is summarised in table 2.

Table 2

The p-function, divided into the normalised c-function and free-rider values

(normalised to the grand coalition).

Normalised c-function, $v(S) = \frac{\bar{v}(S)}{\bar{v}(N)}$	Free-rider values
v({1})=0	
v({2})=0	
v({3})=0	
v({1,2})=1/4	v({3_{FR}})=0.4
v({1,3})=1/4	v({2_{FR} })=0.2
v({2,3})=1/4	v({1_{FR} })=0.15
v({1,2,3})=1	

Note: $S \subseteq N$, where S is a coalition and N is the grand coalition, S_{FR} refers to the coalition being a free-rider on the remainder players.

Table 2 demonstrates that, when for example players 1 and 2 form a coalition and gain ¼, player 3 can by free-riding gain 0.4 (or what corresponds to 40 % of the joint benefits). This is an example of a game with a positive externality since the payoff to player three changes from zero to be positive when player 1 and 2 form a coalition.

For each cooperation structure we would also have corresponding equilibrium fishing efforts. The game satisfies global efficiency since adding players to cooperation always increases total payoffs. In addition the grand coalition can be internal stable (Pintassilgo, 2003) since the sum of free rider values (0.4+0.20+0.15=0.75) is less than 1, thus, the sum of free rider benefits do not exceed the benefits from the grand coalition. It is, therefore, possible to find an allocation of the benefits from the grand coalition, which will not give any player an incentive to free ride on the grand coalition.

In the example, country 2 would receive two units of benefits (e.g. million USD) (see Table 1), whereas by joining together with country 1, they would together receive 4 units of benefits in their two-player coalition. Further, if player 3 could also join the other two countries, the grand coalition payoff would be 10 units.

When analysing cooperative games one needs to decide how the non-members of the coalition will behave. Sometimes it is assumed that the non-member chooses a fishing policy that punishes the members as hard as possible (alpha core) (Chander and Tulkens 1997). Another more economically appealing behaviour, found for example in Kaitala and Lindroos (1998) and Kronbak and Lindroos (2006), is that the non-members and members engage in a competitive game ending up in a Nash equilibrium in between coalitions. This is called a gamma type (γ-type) c-function (Chander & Tulkens 1997, Kronbak and Lindroos 2007).The Nash equilibrium is defined such that it is not profitable, for neither the members nor the non-members, to unilaterally change their fishing policies. This is also often referred to as non-cooperative behaviour.

In-between the full cooperative and the full-non-cooperative games is the literature dealing with coalition formations, where a group of players join together and form a coalition inside which they cooperate. The coalition plays non-cooperatively against the players outside the coalition. This type of literature is mainly applied for determining the bargaining power of the players exploiting the resource (Duarte *et al*. 2000, Arnason *et al*. 2000, Lindroos & Kaitala, 2000).

The following section focuses the attention to the sharing issues, involving cooperative solutions to the games.

3. Sharing of benefits and stability issues

By the application of game theory to bio-economic models it is possible to say something about the likely implications of policy decisions about allocation of rights to harvest species. It is well-established that the cooperative solution yields substantial gains compared to the non-cooperative solution, but it also implies side payments (Munro 2000). In many cases, only by allowing side payment a cooperative solution can be reached. Side payments imply that a transfer of benefits between countries, it must occur if the countries want to reach the mutual best benefits from their joint agreement. The problem relates to the general problem of potential versus actual Pareto efficiency. The cooperative solution results a potential Pareto efficient outcome, but in most cases it requires side payments or sharing of benefits to achieve the actual Pareto improvement. How to determine the actual size of the side-payments or allocation of benefits is the topic for discussion in this section. From real world setting there exist examples, where side payments are difficult to apply; the Arcto-Norwegian cod stock is jointly managed between Norway and Russia, who have different management goals. A sensible economic policy for the Norwegians would appear to be renting out their fishery rights to the resource entirely to Russia which has a flavor of a side payment, but Norway refuse to contemplate such a policy, see Armstrong & Flaaten (1989). Side payments could also exists in the form of trading TACs for different species which is the case in the EU management of different species or indirectly as a common pool of catches for a groups of fishermen for instance in the form of RFMO's of PO's.

Side payments are one way to ensure that a joint outcome is stable solution to the management of a fishery from which no one has the incentive to deviate. An alternative approach is the introduction of threat strategies. This issue will only be touched upon very briefly. Kaitala (1985) introduces threat strategies into game theoretic fishery models. Kaitala suggests that each player establishes a credible system of threats to make an agreement achievable. Kaitala & Pohjola (1988) introduce the trigger-strategies where deviation triggers a switch to play another predefined strategy often the non-cooperative strategy which is then referred to as the threat strategy. The threat broadens the scope for cooperative agreements since they are now threatened by an alternative (non-cooperative) strategy.

The thoughts about threat strategies are slightly connected to the allocation of benefits in the grand coalition, since it in some allocation schemes is crucial to include the alternative to the grand coalition, which is often referred to as a threat point. Kronbak & Lindroos (2007) discuss this in more details.

The literature on the sharing of joint benefits in a fishery dates back to Kaitala & Lindroos (1998) who introduce the theoretical framework theory, ignoring externalities. They concentrate on benefit sharing rules but coalition formation is exogenous. The theoretical framework is further developed by Pintassilgo (2003) who studied the stability of the grand coalition in the presence of externalities in a partition function approach; this study also included endogenous coalition formation but not study the benefit sharing rule. The externalities, the endogenous coalition formation and the sharing rules have been considered in empirical studies applying the c-games in a special issue of Marine Resource Economics in 2000 (Lindroos & Kaitala (2000), Arnason *et al*. (2000), Duarte *et al*. (2000) and Brasão *et al*. (2000)). These studies do, however, not reveal a sharing rule ensuring the grand coalition is stable. Kronbak & Lindroos (2007) introduce a connection between cooperative games (sharing rules) and non-cooperative games (stability) and thereby suggest an alternative sharing rule that takes into account the stability of cooperation when externalities are present. It thus discusses the step from potential Pareto improvement (the grand coalition) to the actual Pareto improvement (the sharing rule ensuring stability).

The introduction of game theory into fishery models has been a major step in the direction of understanding a seemingly irrational, but actual behavior and in understanding the difficulties in reaching a social optimal outcome from the management of shared resource. Due to the spillover effects, which results in stronger free rider incentives, it is hard to achieve a first best solution where a joint agreement exists for exploiting the resources; instead the non-cooperative outcome or smaller coalitions are a result. The free rider incentives are due to that externalities are often present in fishery games. Externalities are defined as if a merger of coalition changes the payoff to a player belonging to a coalition not in the merger. When externalities are present in fisheries games the characteristic function games approach in itself is not fully sufficient. Therefore a merger between the non-cooperative and the cooperative games is necessary. This can be done either in the sharing rules in the characteristic function games, if the purpose is to define the individual pay-offs, or if the purpose is to define the incentives to participate in coalition, the partition function approach is appropriate.

Different sharing rules describe how to share the cooperative benefits between players. Several of these rules have been applied in the literature. Ideally, for policy implications the sharing rules should be related back to the allocation of TACs, these are, however, traditionally are based on biological models and historical catches and not as the first best solution to bio-economic models.

A sharing imputation of a c-game among *n* player is a *n*-dimensional vector $X = (x_1, x_2, \dots, x_n)$, where *X* is the vector and x_i is the share allocated to player *i*. The sharing imputation must satisfy that it is individual rational such that every player of the n players achieve part of the joint benefits and group rational such that all benefits within the joint outcome are shared among the players (no leftovers). Mathematically, this can be written as follows.

$$x_i > 0, \quad 1 = 1,2,\dots,n \qquad \text{(individual rationality)}$$

$$x_1 + x_2 + \dots + x_n = 1 \qquad \text{(group rationality)}$$

4. Sharing rules

4.1 Shapley value

The original contribution of the Shapley value dates back to Shapley (1953). It assigns a value to each player defined as the potential to change the worth of the coalition by joining or leaving it, that is the expected marginal contribution. The Shapley value for player *i* is defined as follows (Aumann and Dréze 1974):

$$x_i = \sum_{s \in K\, i \in s} \frac{(n-|s|)!(|s|-1)!}{n!} v(s) - v(s - \{i\}),$$

where K are the possible coalitions (with n players there is 2^n-1 possible coalitions), n is the number of players in the game, and $|s|$ is the number of players in coalition s. The above formula shows that the Shapley value is determined by the probability of the different coalitions multiplied by the marginal contribution to the coalition by player i.

The Shapley value in our case could be computed as follows, illustrated in table 3.

Table 3

Shapley Values of the normalised example

Order of coalition formation	Player 1	Player 2	Player 3
1,2,3	0	1/4	3/4
1,3,2	0	3/4	1/4
2,1,3	1/4	0	3/4
2,3,1	3/4	0	1/4
3,1,2	1/4	3/4	0
3,2,1	3/4	1/4	0
Shapley value	*1/3*	*1/3*	*1/3*

Note: The Shapley values are calculated as the sum of the above possible combinations divided by the number of possible combinations.

In this example the probability of each coalition formation is equally likely. We sum up the marginal contributions of each country to each coalition and then compute a weighted sum of these marginal contributions, the weight being 1/6 here. The result is the Shapley value.

The Shapley value allocates 1/3 to each country. It is immediately seen that only country 1 is satisfied with its share since it is large than ¼ what it would gain by free-riding. The reason for this is the positive externality in the game, since without this positive externality all players would be satisfied with the Shapley value. In a core-stability sense (cooperative stability) all countries and coalitions would be satisfied with the Shapley value.

The Shapley value has the advantage that it is easy to calculate and can be considered fair since it depends on each player's marginal contribution to the coalition. The problem is that the sharing rules do not take the stability of cooperation into consideration when externalities are present and an allocation based on the Shapley value can therefore result in instable allocations where one or more players has incentive to deviate from the grand coalition. This is a problem that has also arisen in previous empirical studies (Lindroos & Kaitala, 2000; Arnason *et al*., 2000; Duarte *et al*., 2000; Kronbak and Lindroos, 2007), but it has not been recognized (see Kronbak and Lindroos (2007) for further discussions).

4.2 Nucleolus

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

The reasonable set is defined as imputations that satisfy three equations. First, a player receives no more than what the player contributes to the coalition. Second, the imputation is individually rational; that is, all players should be better off 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 a coalition, *s*, can obtain for itself, cased on the characteristic function and the fraction of benefits of cooperation that the imputation w are searching for allocates to the coalition, *s* which corresponds to the sum of allocations to all members in the coalition, *s*.

$$e(s, X) = v(s) - \sum_{i \in s} x_i \ ,$$

The core is defined by the excess being negative and is added as a condition to the reasonable set;

Applying the example presented previously with three players, the core takes the following form:

$$v(\{i\}) - x_i \leq 0 \ \forall i = \{1,2,3\} \text{ (individual rationality)}$$

$$x_1 + x_2 + x_3 = 1 \qquad \text{(group rationality)}$$

$$v(\{1,2\}) - x_1 - x_2 \leq 0$$

$$v(\{1,3\}) - x_1 - x_3 = v(\{1,3\}) - x_1 - (1 - x_1 - x_1) = x_2 - 1 + v(\{1,3\}) \leq 0 \ .$$

$$v(\{2,3\}) - x_2 - x_3 = v(\{2,3\}) - x_2 - (1 - x_1 - x_2) = x_1 - 1 + v(\{2,3\}) \leq 0$$

The core ensures that each player receives at least the payoff that it would have received from playing singleton (the individual rationality). The core ensures that all the cooperative benefits are shared among the players (the group rationality). And finally, the core ensures that the players receive at least what they would have received by joining a two-player coalition (the last three constraints of above)).

The rational *ε*-core is determined by shrinking the boundaries of the core at the same rate until it collapses into either a line or a single point (with three players, more players increases the dimensions of the collapse).

Again applying the example with three players, the rational *ε*-core consists of the imputations *X* that satisfy:

$$-x_1 \leq \varepsilon \text{ , } -x_2 \leq \varepsilon \text{ , } -x_3 \leq \varepsilon$$

$$v(\{1,2\}) - x_1 - x_2 \leq \varepsilon \text{ ,}$$

$$x_2 - 1 + v(\{1,3\}) \leq \varepsilon \text{ ,}$$

$$x_1 - 1 + v(\{2,3\}) \leq \varepsilon \text{ ,}$$

$$x_1 + x_2 + x_3 = 1.$$

The shrinking of the boundaries until it collapses (shrinking further would empty the set) results in the least rational ε-core. If the rational ε-core results in a single point, then this is identical to the nucleolus. If not then the nucleolus is based on the concept of minimising maximum dissatisfaction. This requires a definition of the set of coalitions whose excess can be reduced below the least rational ε-core and finding the max min in this set. This process continues until it collapses to a single point which is referred to as the nucleolus (see Appendix for the necessary definitions and procedures here).

The nucleolus has the advantage of always being in the core and is considered fair. It is technically more difficult to calculate than the Shapley value. It has been applied to fisheries in several papers (Lindroos & Kaitala 2000, Duarte *et al*., 2000; Kronbak & Lindroos, 2007). The disadvantage of the nucleolus is that it is originally defined on games without spillovers or externalities. Therefore, it is not necessarily free rider stable, which leads to the following modification of the sharing allocation.

4.3 Satisfactory nucleolus

Given that the Shapley values and the nucleoli are not necessarily stable against free rider incentives, an alternative distribution is suggested; the satisfactory nucleolus. It is based on a modification of the offset for determine the nucleolus. The satisfactory core is defined by modifying the core to also include the concept of individual satisfaction. The individual satisfaction ensures players are at least as well off as when free riding. This is a parallel to the individual rationality which ensures the players are as well off as when playing as singletons. The breaking point is that players have already agreed to cooperate and if they should sustain to this agreement, they must not be tempted to deviate, and hence the sharing rule should ensure all players receive at least their free rider value. The satisfactory core is defined as follows:

$$e(s,x) = v(s) - \sum_{i \in s} x_i \leq 0$$

$$x_i \geq \frac{v(freerider)}{v(N)} \quad \text{(Individual Satisfaction)}$$

$$x_1 + x_2 + \ldots + x_n = 1,$$

Where *N* is the grand coalition. The satisfactory core deviates from the ordinary core by the individual satisfaction constraint. This constraint ensures that each player receives at least the amount the player would receive by free riding on the grand coalition. One could argue that this condition should be further elaborated to avoid players being tempted to participate in any sub-coalitions compared to the grand coalition and to ensure that remaining coalitions after free riding are stable.

In our specific example, the free rider values are credible threats because all two-player coalitions are stable. This means that if one player leaves the grand coalition the equilibrium will be such that there is a two-player coalition and a singleton. The individual satisfaction defines a set of sharing imputations that are all internal stable, thus ensures that none of the players has an incentive to free ride. The satisfactory nucleolus is now defined similar to the traditional nucleolus in the sense that it is defined as the lexicographic centre of the satisfactory ε-core or as minimising maximum dissatisfaction. For a more technical approach to deriving the satisfactory nucleolus, some terminology is defined in the appendix. The satisfactory rational ε-core as defined as it relates to the example takes the following form:

$$0.25 - x_1 - x_2 \leq \varepsilon,$$

$$x_2 - 1 + 0.25 \leq \varepsilon,$$

$$x_1 - 1 + 0.25 \leq \varepsilon \ ,$$

$$x_1 \geq 0.15 - \varepsilon \ , \ x_2 \geq 0.2 - \varepsilon \ , \ 1 - x_1 - x_2 \geq 0.4 - \varepsilon$$

$$x_1 + x_2 + x_3 = 1.$$

The least rational ε-core corresponds to a value of app. -0.083 and the corresponding value for the satisfactory nucleolus is $x_1 = 0.233$, $x_2 = 0.283$ and $x_3 = 0.483$. The satisfactory nucleolus clearly differs from the traditional nucleolus in its value, it reflects the strong free riding power player 3 has by allocating a large shares (almost 50%) of the joint benefits to this player.

The satisfactory nucleolus has been applied to the case study of sharing cod quotas in the Baltic Sea (Kronbak and Lindroos, 2007). It provides an allocation which is stable to free rider incentives opposite to the allocation of quotas in the past. The advantage of the satisfactory nucleolus is that it explicitly includes the problems of spillovers in resource games, thus if the satisfactory nucleolus exists it is in the core and it is free rider stable. The disadvantages are the complexities in calculating the sharing imputation.

4.4 Almost Ideal Sharing Scheme

The almost ideal sharing scheme (AISS) is a variation of the satisfactory nucleolus, which also recognizes the problems with stability of grand coalitions when externalities are present. It is originally introduced in a working paper by Eyckmans and Finus (2004). They propose a sharing scheme for the distribution of the gains from cooperation where any particular solution belonging to this scheme leads to the set of stable coalitions. The sharing allocation is based on the free rider pay-off plus an additional share of the surplus. Their work is purely theoretical and there is no specific designs and arguments for how to define the surplus allocated in addition to the free rider benefits. One design could be an egalitarian mechanism assuming equal allocation of the surplus. The surplus is equal to the value of the grand coalition minus the sum of the free rider values and as calculated under Table 2, this corresponds to a surplus of 0.25. The AISS assuming an equal split within coalitions in our example would then be the free rider values from each players plus an equal share of the surplus. Thus players 1 will achieve 0.15+0.25/3=0.233, player 2 will achieve 0.283 and player 3 will achieve 0.483, respectively.

The advantage of the AISS is, similar to the satisfactory nucleolus, that it takes free rider threats into consideration in the allocation of benefits. In addition it is easier to calculate compared to the satisfactory nucleolus. The disadvantage is the unclear definition of how the excess is shared among members of the grand coalition. The methodology has been applied in the sharing of benefits in the game amongst countries around the Baltic Sea harvesting Salmon (Kulmala *et al*., 2009).

4.5 Summarising sharing rules

The above section includes a series of sharing rules mentioned and applied in the literature. The following Table 4 provides a summary of the different sharing imputations which has been calculated in relation to the example.

Table 4

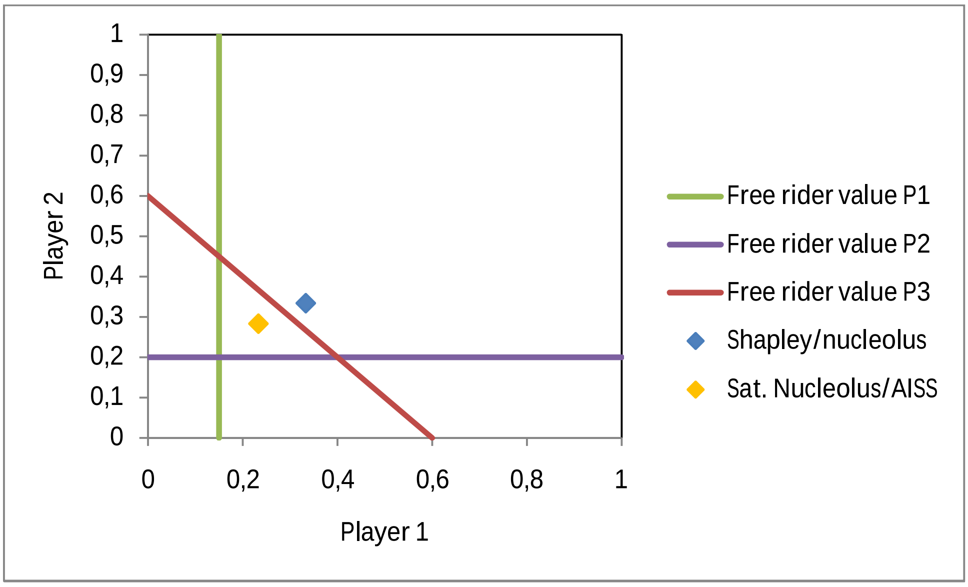
Shapley Values, nucleolus, satisfactory nucleolus and AISS, share of joint benefits.

	Player 1	Player 2	Player 3
Shapley value	1/3	1/3	1/3
nucleolus	1/3	1/3	1/3
Satisfactory nucleolus	0.233	0.283	0.483
AISS egalitarian	0.233	0.283	0.483

The nucleolus and the Shapley values coincide in our example. This is primarily due to the two player coalitions are all having the same bargaining power since they all face the same pay offs. It is not always the case that these two sharing rules will coincide. Also, the satisfactory nucleolus and the AISS applying an egalitarian sharing of the surplus benefits coincide; again this is due to the simple setup of the example. The sharing rules indicates the share of the cooperative benefits that should be allocated to the single players in the game. They do not all al consider the problem of externalities or spillovers in fisheries games. The sharing rules that do not explicitly consider this have the risk of not being internal stable, which is the case for the Shapley value and the nucleolus for the constructed example. Thus, the threat points applied should recognise these special circumstances that relates to games of sharing management rights over fish stocks. These threat points are included in the sharing rules satisfactory nucleolus and AISS with an egalitarian sharing of the surplus. Figure 1 illustrates the free rider threat points and the different sharing rules in the example in a player 1, player 2 diagram. Player 3 will achieve the remainder share of the benefits, thus $x_3 = 1 - x_1 - x_2$, to ensure Pareto efficiency.

Figure 1

Graphical illustration of the free rider values and the sharing rules



From Figure 1 it becomes clear that the Shapley value and the nucleolus are not stable sharing imputations since they do not include the strong bargaining power that player 3 has due to his high free rider value. Thus, these sharing rules allocate a share too small to player 3 to ensure a stable sharing of benefits.

Not all fishery games have possible stable sharing of joint benefits, but it is fairly easy to calculate whether there is a surplus of joint benefits compared to the free rider values. Example of fishery games where there is no stable grand coalition is Lindroos and Kaitala (2000) and Pintassilgo 2003. If the number of players in a game increases, it 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. Olson 1965 also demonstrates that the more players the less likely an agreement is to happen. The example in this paper is limited to three players, argued by the fact that in many 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.

5. Limitations and Related Problems

5.1 Open loop versus closed loop

The above applications of sharing rules in fisheries are based on open loop decisions. A game is referred to as an open loop dynamic game if the players cannot observe the state of the system after the beginning of the game. Players will make decisions only in the beginning of the game and maintain these initial strategies throughout the game even though the preconditions are changing. These types of games are numerically much simpler to solve since it requires optimization only in the beginning of the game. It is necessary to mention that the optimization is throughout the period games are running. From a real world perspective this would require decision of harvest rules into the future, or would require a re-optimization each year, but recalling that a use value of the resource has to be included. Opposite to the open loop games are the closed loop games. In a closed loop dynamic game players have full information on the development of the game (or the evolving of the stock) so far and are able to change strategies during the game. There is thus no commitment to a strategy since the actions change as a function of the state stock. These types of games are numerically very hard to handle since they have to take all future consequences of today's decisions into consideration when optimizing. Thus, the state-of-the art in the literature is to apply constant fishing policies in time. This is easy to implement in reality. However, in theoretical terms dynamic coalition game applications are most likely studied extensively in the near future. Some examples exist, such as Lindroos (2004) who studies the development of Shapley values in time.

5.2 Migratory stock versus shared stocks

Dealing with shared stocks rather than migratory stock simplifies matters since in these cases there is a simultaneous move game amongst a limited number of nations. Within game theory there is a limitation, since it becomes quickly too complicated when dealing with a larger number of agents. Therefore most of the literature on game theory deals with nations rather than vessels as economic agents. Nations would be a simplification in the models but nations are not necessarily representative. Dealing with migratory stock might require sequential move games since different nations harvest in sequences depending on the stocks availability in territorial waters (to read more about sequential games please see Lindroos *et al.* 2007 and Kronbak & Lindroos 2004). In addition migratory stocks have the disadvantage of being in high seas with open access like conditions, in these cases agreements of sharing of benefits becomes more complicated.

5.3 Bycatch of other species

None of the models, which are described in this paper, takes multi-species fishery into account. There is thus a limited application of game theory to multi-species so far, among one of the papers is Kronbak &

Lindroos (*forthcoming*) but this application is to the non-cooperative equilibrium and merely discusses how the number of players affect species extinction. The multispecies problem is a two-fold problem involving both economic and biological interaction. Or it can be regarded as an additional game to take into consideration where fisherman has the choice between different species and can therefore can make parallel fisheries agreement. One way to solve this problem might be to regard vessels as multi-product firms. Applying this settings, for instance to a coalition game, can result in that instead for money transfer btw players to reach stability transfer of TACs between players might occur. In such case threat points might not be unique but be a result of different combinations of species that results in a certain profit level.

5.4 Spatial issues

The spatial distribution of the stock should be taken into account when sharing the TACs. This is a new area for research where there to the authors' knowledge so far only has been published one paper by Bjørndal and Lindroos (2004). The idea is that the location of the stock affects how the TACs are shared between countries. The paper is a two-player game, thus there is a need for this perspective in coalition games.

5.5 New member problem

The new member problem states that an international organisation governing fish stocks should be cautious when deciding on how many countries can participate in the fishery. This also applies to the fisher level. There are some instances, however, where new entrants may stabilise the agreement (Lindroos 2008), but probably in most of the cases new members are a problem. There are also issues related to the rules within the existing members of regional fisheries management organisations that should be taken into account. These rules, for example, whether the existing members need to be unanimous of accepting prospective new entrants, may affect stability of the agreement great deal. In fisheries, most of the models are open membership type, meaning that existing members accept all potential entrants that find it profitable to enter the agreement. There are some recent models like Ekerhovd (2010) that also consider excludable membership, that is, countries may block the membership of some prospective entrants.

5.6 External effects on agreements

External effects on fishery agreements such as climate change, pollution or change in mortality due to diseases might change the preconditions for achieving stable agreements. Thus the likelihood of stable agreements might change as part of changes in the ecosystem. This has been analysed in Brandt and Kronbak (2010) in the case of climate change and its affect on the stability of agreements for the cod in the Baltic fishery. The framework for analysis need to be extended into the area of also including spatial issues since external conditions like e.g. climate change which can change the migratory pattern of species and thereby change the number of countries for which the species is present in the territorial waters.

6. Conclusions

Our review has identified several policy relevant issues emerging from the game theory and fisheries literature. The most important are summarised below.

1. The number of players participating in the fishery needs to be identified. How many fishers, fishing nations and other organisations affecting are there? This is clearly seen e.g. in Pintassilgo *et al*. (2010) where the authors show how the number of players affects the possibilities of achieving international fisheries agreements. For an analysis how different levels affect the games see Kronbak and Lindroos (2006).

2. Determine the species involved; their economic and biological dependencies. Kronbak and Lindroos (*forthcoming*) have studied the number of countries that can be sustained in a fishery with many species. This study is thus clearly linked with recommendation number one above.

3. Existing agreements in the fishery need to be identified. Are there producer organisations, international agreements or some other form of cooperation already taking place? The fisheries games above can be used to calculate how the actual agreements work. If all parties have an agreement but still the results are poor in terms of economics and biology, the agreements need to be reconsidered. An example is found in Kulmala *et al*. (2009) where it is shown that despite of the Baltic Sea agreements, the salmon fishery studied can be described by virtual non-cooperation.

4. Existing management of the fishery. Is the management the same or different for all players? This is an area that has not received very much attention in the literature. Some inspiration for this area can be found in the literature on the benefits of joint enforcement (Kronbak & Lindroos, 2006). There are cases where individual countries have perfect national management systems, but as the resource is shared with another country, international management of the fishery is a disaster.

5. Are the players similar of very different. The game results above critically depend on the heterogeneity of the players. Pintassilgo *et al*. (2010) have studies this issue in detail. Their results can be used to predict how well an agreement would improve the management of the fishery.

6. Determine sharing rules that are accepted by the players. Different sharing rules may affect the stability of cooperation as we have seen above (see also Kronbak & Lindroos, 2007). Therefore, it is essential that participants understand and accept the consequences of the chosen allocation rule.

7. Determine rules how new members can be accepted for the management organisation. Existing members may be made worse off by accepting new members. Therefore, it is essential to have rules how to accept new members, or whether new members should be accepted at all.

8. Determine rules for renegotiation of the agreement. The fish population, economic fundamentals such as fishing costs and prices are likely to change in time. This will change the bargaining positions of the players, and hence the stability of cooperation. Previously successful cooperation may become unsatisfactory for one or several players and vice versa, see Brandt and Kronbak (2009) for an example.

9. Determine monitoring and sanctions, if someone breaks the rules. If there is no incentive to follow the rules, the likelihood of cooperation will be reduced. On the other hand, monitoring is costly. There is no point of having a stable cooperative agreement if it costs too much.

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Appendix – terminology for defining the nucleolus and the satisfactory nucleolus

The reasonable set

A fair allocation which ensures that no-one receives more then the maximum they contribute to the grand coalition.

$$x_i \leq \max_{T \in \Pi^i} \{v(T) - v(T - \{i\})\},$$

Where $\Pi^i = \{S | i \in S \wedge S \subseteq N\}$, N is the set of all players, called the grand coalition, N={1,2,...,n}.

Excess of a coalition

The difference between the fraction of the benefits of cooperation that S can obtain for itself (from the normalised C-function) and the fraction of the benefits of cooperation that x allocates to S.

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

The Core

Imputations that ensures that every coalition receives less benefits than the grand coalition.

$$C^+(0) = \{x \in X | e(S,x) \leq 0 \forall S\}$$

Definition of coalitions set

Define $\sum^0$ as the set of all coalitions that are neither the empty coalition or the grand coalition.

$$\sum{}^0 = \{S | S \subset N, S \neq \emptyset, S \neq N\}$$

The rational **ε**-core

Suppose the boundaries of the core are moved inward with ε.

$$C^+(\varepsilon) = \{x \in X | e(S,x) \leq \varepsilon \forall S \in \textstyle\sum^0\}$$

Defining $\phi_0(x) = \max_{S \in \sum^0} e(S,x)$ allow us to define $C^+(\varepsilon)$ as

$$C^{+}(\varepsilon) = \{x \in X | \phi_0(x) \leq \varepsilon\}$$

The least rational core

Boundaries of the rational core are moved inwards (ε is reduced) as much as possible without violating the condition $\phi_0(x) \leq \varepsilon$.

$$X^1 = C^{+}(\varepsilon_1), \text{ where } \varepsilon_1 = \min_{x \in X} \phi_0(x)$$

Definition

Define $\sum^1$ as the set of all coalitions whose excess can be reduced below ε_1 by an imputation in X^1.

$$\sum^1 = \{S \in \sum^0 | e(S,x) < \varepsilon_1 \text{ for some } x \in X^1\}$$

Definition

Define the maximum excess of coalitions in $\sum^1$

$$\phi_1(x) = \max_{S \in \sum^1} e(S,x)$$

Definition

The minimum of the maximum excess of coalitions in $\sum^1$

$$\varepsilon_2 = \min_{x \in X^1} \phi_1(x)$$

Definition

Let X^2 consist of all imputations at which the maximum excess of coalitions in $\sum^1$ achieves its minimum.

$$\phi_1(x) = \{x \in X^1 | \phi_1(x) = \varepsilon_1\}$$

The nucleolus

Lexicographic center of the core.

Keep on constructing sub-sets of coalitions $\sum^{j}$, excluding coalitions that cannot have excess reduced below ε_j until X^j contains only a single imputation. This imputation is the only imputation that the nucleolus contains. The nucleolus minimizes the maximum dissatisfaction.

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