Coalition Games in Fisheries Economics

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Abstract. We review the literature on coalition games applied in fisheries economics. We first indicate the importance and origin of the theory. Then we compare non-cooperative and cooperative coalition game approaches. Our conclusion is that the non-cooperative and the cooperative approach should be linked together. To achieve this aim future research on stability of cooperative solutions and factors influencing stability is needed.
1 Introduction

The analysis of coalitions has received increasing attention in fisheries economics in the last ten years (Kaitala and Lindroos 1998, Arnason and Magnusson 2000, Lindroos and Kaitala 2000, Lindroos 2004, Burton 2003, Brasão et al. 2000). The need for the research of cooperative fisheries management arises from the current practice of international negotiations and implementation of multi-country fisheries agreements. In several locations worldwide, fishing nations aim at organizing local multi-nation fisheries such that the outcome would satisfy all nations interested in participating in the fishery. In this process, it becomes pertinent to not only consider strategic importance of the international fisheries agreements to individual countries, but also to groups of countries.

In the recent literature there has been two main directions following the traditional division in game theory. Firstly, non-cooperative coalition games have concentrated on the endogenous formation of coalitions and coalition structures. Secondly, cooperative fisheries coalition games have concentrated on the allocation of cooperative benefits to different countries involved. We shall follow this division in the present review.

The content of the paper is as follows. In chapter 2 we demonstrate why coalition games are needed and recall the first applications of coalition fisheries games. Chapter 3 discusses the most recent developments in finding equilibrium coalition structures for non-cooperative coalition fisheries games. Chapter 4 then discusses and contrasts the cooperative coalition games applied in the theory and applications of international fisheries management. Finally, chapter 5 concludes and in particular discusses the need for merging these two approaches. Indeed, it is often difficult to make distinction between purely cooperative or non-cooperative modes of games. Therefore, we conclude that the related game theory is not fully mature and developing a unifying framework would be essential.
2 The need for coalition games

Many important contributions in fisheries economics can be traced back to Professor Gordon Munro’s exceptional research activity. The analysis of coalition games is not an exception in this respect. He was alert when the negotiations processes on the United Nation’s New Law of the Sea were active (Kaitala and Munro 1993). Observing the processes from outside of the negotiation process professor Munro foresaw that many interesting scientific problems arose during this process. One of these was the pop-up of different interest groups in the negotiations. This observation leads to the conclusion that the analysis of coalitions should be brought into fisheries economics (Kaitala and Munro 1995). The emergence of a new international fisheries agreement on straddling and highly migratory fish stocks (UN 1995) confirmed that Gordon Munro was very right in advertising that the new legal environment for the management and utilization of marine resources left behind a bunch of economic problems that need to be fully understood (Kaitala and Munro 1997, Kaitala and Lindroos 1998, Bjørndal et al. 2000, Brasão et al. 2000).

The theory of fisheries games in 1995 had mainly been built on two-player games (Munro 1979, Clark 1980, for reviews, see Munro 1990 and Sumaila 1999), which has its roots in completing the economic theory related to the property right problems created by the establishment of the Exclusive Economic Zones and the former United Nation’s Law of the Sea (1982). The emphasis was in defining fair strategies for exploiting shared fisheries where the number of countries exploiting the stocks was fairly low, and in many cases equal to two. However, the agreement on straddling and highly migratory fish stocks made it necessary to study game-theoretic models of more than two players. This was because the potential number of countries involved in high seas fisheries agreements can be very large. The negotiations on high seas fisheries thereby created the foundation for discussing coalition formation and setting harvesting strategies.
3 Non-cooperative coalition games: coalition formation and setting harvesting strategies

The merits of applying coalition games in analyzing fisheries economics is next illustrated by a simplified example. Let us assume that we have four countries exploiting a common fish stock. (This is close to the case of exploitation of Norwegian Spring-Spawning Herring (Bjorndal et al. 2000).) The countries aim at maximizing their individual net present values from the fishery. Each country participates in international negotiations where countries may or may not be successful in achieving either bilateral or multilateral agreements.

This kind of multi-agent decision making problem can be formulated as a coalition game (Mesterton-Gibbons 1993). In a four-player example there are 15 possible coalitions that can be formed. Further, there are several coalition structures that describe all possible outcomes of the negotiations. Coalition structures can be characterized as follows:

Let us assume that countries 1 and 2 find it beneficial to form a coalition (1,2). Thus, countries 1 and 2 act as a cooperative unit. The remaining two countries now have the option to either sign a bilateral agreement with each other and thus form a coalition (3,4) or formulate their own unilateral harvest strategies. Thus, in this case we have two possible coalition structures:

(1,2), (3,4)
(1,2), (3), (4)

Clearly the benefits of coalition (1,2) must depend on the harvest decisions of the outside countries 3 and 4 since externalities are present in fisheries. If countries 3 and 4 sign a bilateral agreement then the fish stock and benefits are typically larger than in the case where the outside countries 3 and 4 choose their fishing strategies attempting to unilaterally maximize their own benefits individually.
The coalition game above can be solved as follows:

We can think of the coalition game in two stages. In the first stage, the countries form coalitions with one another. In the second stage countries and coalitions compute their best strategies. The game is solved backwards.

Countries within coalition (1,2) maximize their joint benefits taking into account that they have to play against either coalition (3,4) or against two individual countries (3) and (4). The result will be a Nash equilibrium of the game where it is not profitable for any of the coalitions or countries to unilaterally deviate from the equilibrium strategies.

The procedure for solving the game has to be repeated for each possible coalition structure. Having solved all these games allows us to proceed to stage 1 to find the equilibrium coalition structure. Of course there may exist several equilibrium coalition structures, one equilibrium, or none at all.

The coalition is said to be stable if there is no country that finds it optimal to join the coalition (external stability) and if no country within the coalition finds it optimal to leave the coalition (internal stability). Other ways of defining stability of coalitions also exist, but these are not addressed in the current review (see e.g. Finus 2001).

The general framework of coalition fisheries games has been studied in particular by Pintassilgo (2003) who brought the theory a major leap forwards. He introduced the partition function approach to these games and hence formalised the existing applications on several species.

Arnason and Magnusson (2000), Lindroos and Kaitala (2000) and Lindroos (2004) analysed Norwegian spring-spawning herring fishery as a coalition game. Arnason and Magnusson showed that Norway is a veto-country in the stability sense in the herring fishery. This follows from the fact that all stable coalitions include Norway as a member. Lindroos and Kaitala (2000) were the first to compute Nash equilibria for coalition fisheries games. Finally, Lindroos (2004b) studied the connections between safe minimum biological levels (SMBL or Blim) and stability of full cooperation.
Example 1
We use the analysis of the Norwegian Spring-Spawning Herring Fishery to illustrate the use of coalition games in fisheries economics (Lindroos and Kaitala 2000). Table 1 summarizes the main results, indicating that full cooperation is not stable. It follows that it is not possible for all countries to sign a multilateral agreement since the incentives to free-ride are large.

Table 1

<table>
<thead>
<tr>
<th>Coalition</th>
<th>Value</th>
<th>Free rider value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>4878</td>
<td></td>
</tr>
<tr>
<td>(2)</td>
<td>2313</td>
<td></td>
</tr>
<tr>
<td>(3)</td>
<td>896</td>
<td></td>
</tr>
<tr>
<td>(1,2)</td>
<td>19562</td>
<td>14534 (country 3)</td>
</tr>
<tr>
<td>(1,3)</td>
<td>18141</td>
<td>17544 (country 2)</td>
</tr>
<tr>
<td>(2,3)</td>
<td>17544</td>
<td>18141 (country 1)</td>
</tr>
<tr>
<td>(1,2,3)</td>
<td>44494</td>
<td>50219 (sum of above)</td>
</tr>
</tbody>
</table>

Note: Values are in million NOK.
Source: Lindroos and Kaitala (2000)

Table 1 illustrates the value of the different coalitions. It is clearly seen that by coordinating effort (joining a coalition) the payoff to the group increases compared to a non-cooperative solution. This is the main motivation for discussing coalitions. What is of particular interest in table 1 are the values, which the singleton outside a two-player coalition, called free rider, is able to receive. This differs from the values the players can receive, when they all act as singletons. The difference is, as discussed earlier, caused by externalities being present in fisheries. If a player receives a payoff in the grand coalition which is smaller than what the player can receive from free riding on the grand coalition, then the player will not join the grand coalition (assuming rationality). Therefore, if and only if the benefits from the grand coalition exceed the sum of benefits from free riding, then there are enough benefits in the grand coalition to be distributed in a satisfactory way, such that the grand coalition is
stable (Pintassilgo 2003). Thus in the example shown in table 1 the full cooperation is not stable.

Brasão et al. (2000) applied the coalition game approach to Northern Atlantic bluefin tuna fisheries. They constructed a dynamic model where they assumed that non-cooperative behaviour was equal to open access. Further, they studied the problem of new members (Kaitala and Munro 1993 introduced new member problem) into regional fisheries management organisations.

The new member problem follows from the UN 1995 Agreement on straddling and highly migratory fish stocks. According to the agreement any country with real interest in the fishery can participate and thereby receive some share of the benefits. However, Kaitala and Munro (1993) showed that this could lead to a situation close to open access and clearly there must be some mechanisms to protect the fishery from a too large number of countries exploiting it. Among others a membership fee has been suggested as this kind of a mechanism.

In the context of coalitions allowing for new members would mean that the stability properties of various coalitions would change if a new member entered the fishery. Lindroos (2002) has shown that this may even lead to a situation where a new member improves stability of cooperation within a regional fisheries management organisation. However, it may also be that the appearance of a new member would lead to another competing organisation that would play against the original one, if one or several of the original members would join the new member. Hannesson (1997) showed that generally the incentives to deviate from full cooperation increases with the number of players.

Kronbak and Lindroos (2003) combined the enforcement of regulation with the coalition formation by setting up a one shot game with four stages. This involves a model where two different groups of agents are present, namely the authorities and the fishermen. These two groups act sequentially as in two ordinary coalition games. Firstly, a two stage model for authorities is solved, where they form coalitions and then compute their best level of enforcement effort to be applied. Secondly, a two
stage model for fishermen is solved; fishermen determine their coalition formation and then their best harvest strategies are computed.

4 Cooperative coalition games: sharing of benefits

The previous chapter described a non-cooperative game in two stages. However, a third stage could also be incorporated in fisheries coalition games. This is the sharing of cooperative benefits. Typically, the models advice that cooperation between all countries involved gives the largest overall benefits. However, the tragedy of the commons and prisoner’s dilemma types of games predict that it will be extremely difficult or even impossible to escape non-cooperation. Often this can be avoided by allowing for side payments and thereby a redistribution of benefits inside the coalition. Munro (1979) showed for a two-player game the usefulness of side payments.

Sharing of cooperative benefits can be introduced in coalition games by using cooperative game theory. In particular, cooperative game theory offers several axiomatic solution concepts that can be used to compute the shares of cooperative benefits for each country. These solutions include Shapley value (probably the most used, see Shapley 1953), nucleolus (Schmeidler 1969) and tau-value (Tijs 1987). 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. The nucleolus minimizes the dissatisfaction of the most dissatisfied coalition. The tau-value is based on the Kalai-Smorodinsky bargaining solution (Kalai and Smorodinsky 1975).

Having decided upon the cooperative solution it is then clear that it will affect the decisions made in earlier stages 1 and 2. Note that stage 3 can not be optimized; there is no optimal way to share benefits. However, it is possible to compare different solution concepts with respect to their stability properties, i.e. which cooperative solutions achieve full cooperation.

Kaitala and Munro (1995) analysed a dynamic cooperative game allowing for coalitions between three countries. They already correctly anticipated the results that were later formalised by Kaitala and Lindroos (1998). Kaitala and Lindroos (1998)
applied two cooperative solutions to the game proposed by Kaitala and Munro (1995) and showed that the cooperative benefits should be shared differently than in the earlier two player games. The dominating coastal country of the high seas fishery game would require more than third of the benefits since its contribution to each possible coalition is the largest.

Lindroos (2004a) extended the model to four players and assumed that coalition formation is restricted such that coastal states and distant water fishing nations only negotiate as a group. Lindroos (2004a) applied the concept of veto-coalitions, that is, countries or coalitions that are essential to the game either to make a coalition stable or to create a positive value for a coalition. The concept of veto-coalitions is connected to the study of Arnason and Magnusson (2000) where Norway was found to be a veto-country in stability sense. However, in Lindroos (2004a) veto-coalition means a coalition with positive bargaining strength.

Kennedy (2003) applied coalition games to the international mackerel fishery. He applied the coalition-proof Nash equilibrium approach for the first time to fisheries coalition games and in addition various cooperative solutions.

Among other previous empirical work is the determination of the Shapley value to the players participating in the coalition game of the Norwegian spring-spawning herring (Arnason, Magnusson & Agnarsson 2000) and the evaluation of the Shapley value and the nucleolus to players in the Northern Atlantic bluefin tuna fishery (Duarte et al. 2000). Brasão et al. (2000) also applies the coalition game to the Northern Atlantic bluefin tuna. They recognize the instability of the Shapley value due to free rider incentives and they instead suggest a stable non-cooperative feedback Nash with side payments. Exactly the instability of the sharing rules due to free rider incentives leads to the future challenges.

5 Future challenges: merger between non-cooperative and cooperative fisheries game theory

What distinguish fisheries coalition game from many other coalition games is that externalities are present in fisheries. If externalities are not present the decisions made
by the coalitions can be assumed to be independent of the actions by the non-members (Greenberg 1994). If, however, externalities are present, as in fisheries coalition games, then the most important challenge in general is the merger between non-cooperative and cooperative coalition games. There is a large literature on both sides of coalition theory and it is fairly well understood, but there are several aspects that need a combined analysis. Kronbak and Lindroos (2005) provide an analysis of the stability properties of nucleolus and Shapley value by showing that the basic idea for the two solution concepts, namely the ability to make a credible threat, can be undermined if externalities are present. Kronbak and Lindroos (2005) develop an alternative sharing rule by merging the non-cooperative and the cooperative game applying the free rider values as threats. They use the Baltic cod as an illustrative example.

**Example 2.**

This example illustrates, by applying the results from the Baltic Sea cod fishery (Kronbak and Lindroos 2005), how instability can be imposed by the sharing rules on an otherwise stable grand coalition.

<table>
<thead>
<tr>
<th>Player</th>
<th>Shapley value</th>
<th>nucleolus</th>
<th>Free rider shares</th>
<th>Satisfactory nucleolus</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>35.9 %</td>
<td>33.3 %</td>
<td>38.1 %</td>
<td>40.3 %</td>
</tr>
<tr>
<td>2</td>
<td>32.3 %</td>
<td>33.3 %</td>
<td>28.2 %</td>
<td>30.4 %</td>
</tr>
<tr>
<td>3</td>
<td>31.8 %</td>
<td>33.3 %</td>
<td>27.1 %</td>
<td>29.3 %</td>
</tr>
</tbody>
</table>

*Note: The results are indicated as in percentage of the benefits in the grand coalition. The numbers are subject to rounding.*

*Source: Kronbak and Lindroos (2005)*

Table 2 shows in percentage how large share of the grand coalition, that each player should receive given different sharing rules or free riding. The grand coalition in itself
is stable since the benefits exceed the sum of benefits from free riding.\(^1\) Instability does, however, occur if the benefits in the grand coalition are shared according to the Shapley value or the nucleolus. The reason for this is that they are not taking externalities into account, which changes the belief of, what is a credible threat. Applying the free rider value as a credible threat instead of the singleton value, allows Kronbak and Lindroos (2005) to develop an alternative sharing rule, the satisfactory nucleolus, which is stable to free riding.

Comparing the above table 2 with table 1 we immediately notice an important difference with respect to stability. All previous fisheries coalition games have predicted an unstable grand coalition (full cooperation) like Lindroos and Kaitala (2000) illustrated in table 1. However, Kronbak and Lindroos (2005) predict a stable grand coalition. This raises an important question for future research: What factors influence stability of full cooperation? These may include biological or economic factors or a combination of these, bioeconomic factors.

Another important future challenge is time consistency in dynamic coalition games. Dementieva (2004) provides new methods for cooperative multi-stage games. However, there is a strong need to incorporate these methods into the theory of non-cooperative coalition games.

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\(^1\) The stability of the grand coalition can be verified by the fact that there exists a sharing rule (satisfactory nucleolus) where the shares to each player exceed the free rider shares.
References


