4. Application of Partition Function Games to the Management of Straddling Fish Stocks

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Abstract. The formation of coalitions among fishing States is a central issue in straddling stock fisheries. In this chapter, this is approached through a game in partition function form. The game is applied to a fishery represented by the classical Gordon-Schaefer bioeconomic model and to the North Atlantic bluefin tuna fishery. Both cases show very pessimistic prospects regarding the cooperative management of the fish resources. This study concludes that the breakdown of cooperative agreements on straddling stock fisheries is a very likely scenario if countries can adopt free ride strategies.

4.1 Introduction

This chapter addresses straddling stock fisheries through coalition games. Straddling fish stocks are a special category of internationally shared fishery resources that straddle exclusive economic zones (territorial seas claimed by coastal States) and the adjacent high seas. These species, usually targeted by both coastal States and distant water fishing States, became increasingly disputed after the establishment of exclusive economic zones by the United Nations Convention on the Law of the Sea (United Nations 1982). Lack of cooperation between coastal States and distant water fishing States has led to the overexploitation of many stocks worldwide.

Munro (1999) refers to the Alaska pollock fishery in the Bering Sea as a paradigmatic example of noncooperative behavior among fishing States and consequent stock overexploitation. A significant part of this straddling fish stock, one of the largest groundfish resources in the world, straddles the exclusive economic zone of the United States of America and a high seas enclave between the United States and Russian exclusive economic zones commonly known as the Doughnut Hole. The fishing pressure on the high seas portion of the stock exerted by distant water fishing States after 1984 resulted in the depletion of the stock in the early 1990s. The increasing tension between the United States and distant water fishing States led the United States coastguards to seize several foreign fishing vessels allegedly using the Doughnut Hole as a base for fishing operations within United States waters. In 1992, after the stock crash, all States involved in the fishery reached an agreement to impose a fishing moratorium in the Doughnut Hole. Another classical example, given by Munro (1999), concerns the groundfish stocks on the Grand Banks of Newfoundland. The lack of cooperation between Canada and the European Union led to the overexploitation of the stocks and to conflicts that reached a climax in 1995 when Canadian authorities arrested a Spanish vessel in international waters.
The economic and biological overexploitation of the stocks and the increasing conflicts among countries, often called “international fish wars”, induced the United Nations to convene the United Nations Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks (1993–1995). In 1995 the conference adopted the United Nations Fish Stocks Agreement\(^2\) (United Nations 1995), which entered into force in 2001. The core of the agreement consists of placing regional fisheries management organizations (RFMOs) as the basic cells for the management of these marine resources. These organizations should integrate both the coastal States and the distant water fishing States effectively interested in the fishery. According to Munro (2006), the United Nations Fish Stocks Agreement left a few problems unsolved that may undermine cooperative agreements achieved under the aegis of RFMOs. One problem is the possibility of prospective new members wanting to join an RFMO and share the harvest following recovery of the stock, thus reaping the benefits of stock management without having borne any of the cost of the investment (free riding). Another problem is the one posed by nonmembers who do not follow an RFMO management regime and thus behave noncooperatively when exploiting the fishery resources in their exclusive economic zones or in the high seas. Munro (2006) refers to the Commission for the Conservation of Southern Bluefin Tuna as an example where both these problems have surfaced.

The economics of straddling stock fisheries is based on coalition games. In this chapter the main studies on coalition games applied to the management of straddling fish stocks are reviewed. The core aim of the chapter is to explore the potential of partition function games, a class of coalition games recently introduced into the fisheries literature. In these games the payoff for each player is defined by a partition function that depends not only on the coalition the player belongs to but also on the way the other players form coalitions. Partition function games have been suggested for cases in which coalition formation produces externalities that affect nonmembers (Yi 1997). This is a typical situation in the management of straddling fish stocks under RFMOs. The more RFMO member players the better for nonmembers, as they can adopt free rider strategies. Thus, partition function games are an appropriate framework to address free rider problems faced by RFMOs. In the present chapter a partition function game on a straddling stock fishery is defined. In addition, the stability of cooperative agreements and the equilibrium of the game are analyzed.

The chapter is structured as follows. A brief revision of coalition games on straddling fish stocks is first presented. This is followed by a section on partition function games, in which the relevance of these games is discussed and the main concepts defined. Next, the partition function game used in the chapter is presented, followed by two applications: a straddling stock fishery represented by the classical Gordon-Schaefer model, and the North Atlantic bluefin tuna fishery. The chapter concludes with a discussion of the main findings and policy recommendations.
4.2 Coalition games

A straddling stock fishery usually involves many countries or fleets. In economic game theory the analysis of games in which the number of players exceeds two requires analysis of coalitions. A coalition means a subset of the set of players. Two or more countries are considered to form a coalition if they ratify (or sign) a multilateral agreement on the particular fishery.

Three types of coalition scenarios may result. If all parties concerned sign the agreement the situation is denoted as full cooperation, and a grand coalition is said to be formed. If some countries are left outside the agreement the situation is denoted as partial cooperation and outsiders may act as free riders. Finally, in the case of noncooperation there are no agreements between the countries, and each is only interested in maximizing individual benefit from the fishery.

Based on the three possible outcomes described above a characteristic function of the game can be established. The characteristic function assigns a value to each possible coalition. The value in the case of straddling fish stocks is, generally, interpreted as the net present value of the fishery to a certain coalition.

The value for coalition members depends on the particular behavior of nonmembers. The different assumptions about their behavior give rise to the $\alpha$, $\beta$, and $\gamma$ characteristic functions. The $\alpha$ and $\beta$ characteristic functions assume that the nonmembers jointly try to punish the coalition members. The problem with this assumption in the context of international fisheries games is that the punishments decrease the payoff of the nonmembers. Therefore, the $\gamma$-characteristic function, introduced by Chander and Tulkens (1995), is typically preferred. The assumption made by the authors is that nonmembers play as singletons and adopt individually best-reply strategies against the coalition. This results in a Nash equilibrium between the coalition and the nonmembers.

An example of a $\gamma$-characteristic function based on a game between three players exploiting Norwegian spring-spawning herring (Lindroos and Kaitala 2000) is given in Table 4.1. The players are Norway, Iceland, and the European Union (EU).

**[Table 4.1 about here]**

In Table 4.1, the first value (US$6,800 million) corresponds to the payoff of the grand coalition formed by all the players. This payoff is calculated by maximizing the joint net present value of profits over a period of 50 years. Under the full cooperative case, the stock level in the long run is the highest compared to the partial and noncooperative cases. The next three values are the payoffs of the two-player coalitions under partial cooperation. These values result from the Nash equilibrium of the game among a two-player coalition, maximizing its joint benefits, and a single country (free rider). The last three values give the noncooperative equilibrium payoffs. Clearly, countries gain by joining together: for example, a coalition of Norway and Iceland would receive
$3,000 million compared to $1,100 million, the sum of their payoffs under noncooperation. Whether a grand coalition can be formed is a more complicated problem. In this case, the conditions when the grand coalition would be stable need to be defined. This is discussed in detail in section 4.4. The following sections present an overview of coalition game literature. See also Lindroos, Kronbak, and Kaitala (2006) for a detailed and more technical review.

Kaitala and Lindroos (1998) introduced coalition games to the economic analysis of straddling stocks and fisheries economics in general by using a three-player model. Their main result is that there is a partial cooperation equilibrium stock level that is higher than the noncooperative stock level (Clark 1980), though lower than the cooperative stock level (Clark and Munro 1975). They also applied Shapley value and nucleolus as cooperative solutions to the sharing of full cooperative benefits. Contrary to previous results, uneven distribution of benefits was suggested due to coalitional bargaining power differences.

Lindroos (2004a) extended the Kaitala-Lindroos model (1998) by allowing for restricted coalition formation in a four-player game. This was analyzed in the context of straddling stock negotiations where distant water fishing States negotiated with coastal States. The main result was that, by joining together, distant water fishing States gained compared to unrestricted negotiations. Arnason, Magnusson, and Agnarsson (2000) studied the case of Atlanto-Scandian herring and found that Norway was a crucial country for any coalition to be stable. Their findings relate to those of Lindroos (2004a), who considered the possibility of veto countries. The effect of uncertainty and selectivity was studied by Lindroos (2004b). He showed that the safe minimum economic stock level that would maximize the possibilities for cooperation was higher than the safe minimum biological level (precautionary level).

Kennedy (2003) applied the concept of coalition-proof equilibrium to the Northeast Atlantic mackerel fishery. Sang Kwon (2006), in one of the most recent applications of coalition games to straddling stocks, extended the Levhari-Mirman (1980) model to include coalitions.

4.3 Partition function games

Characteristic function games have been applied to straddling stock fisheries since the late 1990s. Nonetheless, as observed by Greenberg (1994), the framework of a characteristic function approach, although sufficiently general to encompass many contributions of coalition formation theory, is not fully satisfactory. Most importantly, it ignores the possibility of externalities among coalitions, that is, the effects that coalition mergers have on the payoffs of players who belong to the other coalitions.

**Definition 1.** Externalities are present, in a game in coalition form, if and only if there is at least a merger of coalitions that changes the payoff of a player belonging to a coalition not involved in the merger. If the merger increases (decreases) the payoff of the player, the externality is considered as positive (negative).
In the context of straddling fish stock management through RFMOs, externalities are generally present. In fact, as these organizations tend to adopt conservative management strategies, nonmembers are typically better off when more players become members, as free rider strategies can be adopted. Therefore, when a player joins an RFMO it generally creates a positive externality for nonmembers.

According to Yi (1997), the formation of economic coalitions with externalities has opened a new strand of literature on noncooperative game theory. Most studies (for example Bloch 1996, Yi 1996) are centered on finding the equilibrium number and size of coalitions and share a common two-stage game framework. In the first stage players form coalitions, whereas in the second-stage coalitions engage in noncooperative behavior. The coalition payoffs are represented by a partition function (definition 3). This function assigns a value to each coalition as a function of the entire coalition structure (definition 2). Therefore, it captures the externalities across coalitions that are assumed to be absent in the characteristic function.

**Definition 2.** A coalition structure \( C = \{S_1, S_2, \ldots, S_z\} \) is a set of coalitions that altogether integrates all the players, with each player belonging to only one coalition.

**Definition 3.** The partition function \( \Pi(S_k; C) \) yields the payoff of coalition \( S_k \), which is an element of the coalition structure \( C = \{S_1, S_2, \ldots, S_z\} \). The payoff of player \( i \), which is a member of coalition \( S_k \), is given by the per-member partition function \( \pi_i(S_k; C) \).

Recently, games in partition function form have been applied to internationally shared fish stocks. Pintassilgo (2003) models straddling stock fisheries as a partition function game and derives general results regarding the stability of coalition structures and the equilibrium of the game. The author explores, in particular, the case in which positive externalities are present. An application to the North Atlantic bluefin tuna fishery is undertaken using an age-structured, multigear bioeconomic model. Pham Do and Folmer (2003) study the feasibility of partial cooperation and its impacts on fishing effort through a game in partition function form. Using a static model, general results on the coalition structure in the competitive equilibrium are derived.

### 4.4 Stylized game

In this section, the game framework used by Pintassilgo (2003) is described. This will be applied to specific bioeconomic fishery models in the following sections. Assume that an RFMO is established with the purpose of managing and conserving a straddling fish stock. Consider a two-stage game and a finite number of players. In the first stage, each player decides whether to become a member of the RFMO or to remain a nonmember. As nonmembers typically adopt noncooperative behavior and do not join together, it is assumed that they will act individually as singletons. This is a standard assumption in the literature on international environmental agreements (Finus 2001). In particular, Chander and Tulkens (1997) adopt it in modeling an
economy with multilateral externalities. The authors assume that when a coalition is formed the players outside the coalition adopt only individual best-reply strategies. According to this assumption, coalition payoffs are described by a γ-characteristic function.

Regarding the rule of coalition formation, the simultaneous-move open membership game (Yi 1997) is assumed. Under this rule, the membership of each coalition is open to all players who are willing to follow its strategies. This game is designed to model an institutional environment in which players are allowed to form coalitions freely, as long as no player is excluded from joining any coalition. Thus, any player can choose to be either a member or a nonmember of the RFMO. This assumption is clearly within the legal framework set by the United Nations Fish Stocks Agreement. According to Article 8(3), any State with a real interest in the fisheries concerned should not be precluded from becoming a member of the regional RFMO (United Nations 1995). Furthermore, the agreement appears to leave open the possibility of nonmembers fishing in their exclusive economic zones or in the high seas (Munro 1999).

In the second stage it is assumed that the grand coalition members act cooperatively by choosing the fishing strategy that maximizes their aggregate payoff. For all the other coalition structures, each coalition chooses the strategy that maximizes its own payoff given the behavior of the remaining players. This noncooperative behavior leads to a noncooperative solution for each coalition structure, assumed to be unique. Thus, the coalition payoffs in the second stage can be defined as a partition function. Given the partition function, which yields the equilibrium payoffs of the second-stage game, the equilibrium coalition structures of the first-stage game are the Nash equilibrium outcomes of the open membership game of coalition formation.

An important issue that emerges by setting a coalition approach to a straddling stock fishery is the coalition structure stability. As the United Nations Fish Stocks Agreement calls for cooperative management, special interest is centered on the stability of the grand coalition. According to Greenberg (1994), since the merger of players into an RFMO tends to create positive externalities for nonmembers, the analysis of stability based on single-player deviations emerges naturally. Moreover, in the context of positive externalities, Yi (1997) refers to the concept of stand-alone stability as being particularly useful in characterizing equilibrium coalition structures. This concept is defined as follows.

**Definition 4.** A coalition structure is stand-alone stable if and only if no player finds it profitable to leave its coalition to form a singleton (one-player) coalition, holding the rest of the coalition structure constant (including its former coalition). In the case of the grand coalition, this occurs when no player is interested in leaving the cooperative agreement to adopt free rider behavior.

The following proposition, presented by Pintassilgo (2003), establishes a condition under which a given coalition structure is not stand-alone stable.

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Proposition 1. A sufficient condition for a coalition structure not to be stand-alone stable is that the sum of the payoffs of the singleton coalitions, resulting from unilateral deviations from any of its coalitions, exceeds the value of that coalition.

This proposition provides a tool to determine those cases in which no sharing rule can make a coalition structure stand-alone stable. Specifically, it can be used to assess the possibility of a stable cooperative agreement.

4.5 Application 1: A classical bioeconomic model

The game setting established in the previous section is now applied to a straddling fish stock fishery represented by the classical Gordon-Schaefer bioeconomic model (Gordon 1954). Due to its simplicity, this static model is commonly used in game-theoretic approaches to internationally shared fish resources (for example Ruseski 1998; Lindroos 2002).

Consider $n$ ex ante symmetric players (fleets/countries) in a straddling fish stock fishery. The fish stock dynamics follow the standard Schaefer model (Schaefer 1954), which can be represented through the following equations:

$\frac{dX}{dt} = G(X) - \sum_{i=1}^{n} H_i$ \hspace{1cm} (4.1)

$G(X) = rX \left( 1 - \frac{X}{k} \right)$ \hspace{1cm} (4.2)

$H_i = qE_i X$ \hspace{1cm} (4.3)

where $X$ represents fish stock biomass; $t$ the time; $G(X)$ the logistic growth function; $r$ the intrinsic growth rate of fish; $k$ the carrying capacity of the ecosystem; $H_i$ the harvest of player $i$; $q$ the catchability coefficient; and $E_i$ the fishing effort of player $i$.

According to (4.1), the variation of the stock in time is given by the difference between stock growth and total harvest. Stock growth is defined by a logistic function (4.2). This is an inverted U-shaped function. Stock growth increases as the stock level rises to a maximum value, often designated as maximum sustainable yield. As the stock continues to increase the growth starts to decrease, and upon reaching zero, the stock stabilizes at the carrying capacity of the ecosystem. Thus, for low levels the fish multiply, but once they begin to compete for food growth reduces and the stock tends to the level that can be sustained by the environment. The harvest function (4.3) indicates that the harvest of each player increases with stock level and fishing effort – an aggregate measure of the inputs devoted to harvesting, such as days at sea.

Equations (4.1) to (4.3) can be used to determine the equilibrium, or steady state, stock level that corresponds to a given fishing effort that is constant through time. This steady state relation is given by:
As expected, (4.4) indicates a negative relation between the equilibrium stock level and the players’ fishing effort.

Assuming constant price and cost per unit of effort, the aggregate economic rent from the fishery is:

\[
ER = p \sum_{i=1}^{n} H_i - c \sum_{i=1}^{n} E_i
\]  

(4.5)

where \( ER \) denotes the aggregate economic rent; \( p \) the price; and \( c \) the cost per unit of effort.

Formalizing the economic rent, or economic profit, is the most common way to introduce the fishery economic dimension in bioeconomic modeling. Herein, the standard assumption that agents maximize their profits is adopted.

The Gordon-Schaefer model is still the main reference in theoretical approaches to fisheries bioeconomics. This aggregated model has shown significant potential to demonstrate fundamental economic principles in fisheries management. In particular, it has been the principal bioeconomic model used in addressing noncooperative management of internationally shared stocks (Munro 1999). Nonetheless, the scope of application of this model to empirical studies is very limited, due to its simplicity.

Consider the two-stage framework presented in the previous section. The per-member partition function is determined assuming that each coalition chooses the fishing strategy that maximizes its steady state economic profit, given the behavior of other coalitions. Furthermore, as players are ex ante symmetric, an equal sharing of coalition payoffs is assumed.

In the case of full cooperation, all players adhere to the RFMO. This grand coalition maximizes its steady state profit (4.5). The corresponding aggregate fishing effort and the payoff received by each member are given respectively by:

\[
E = \frac{r}{2q} (1 - b)
\]  

(4.6)

\[
\pi = \frac{1}{n} (pqk - c) \frac{r}{4q} (1 - b)
\]  

(4.7)

where \( b = \frac{c}{pqk} \). This is usually designated an “inverse efficiency parameter”, as it increases with the cost per unit of effort and decreases with price and catchability coefficient. Therefore the higher \( b \) the lower players’ efficiency.
As expected the payoff decreases with the number of players and the cost per unit of effort, and increases with the remaining parameters (price, catchability coefficient, intrinsic growth rate of fish, and carrying capacity of the ecosystem).

In the partial cooperation scenario, a coalition of two or more RFMO members plays against singleton nonmembers. In the Nash equilibrium, the fishing effort of each coalition is the following:

\[
E = \frac{r}{(m+2)q}(1-b)
\]  
(4.8)

where \( m \) denotes the number of nonmembers. Hence, \( n-m \) represents the number of RFMO members, and \( m+1 \) the number of coalitions.

The per-member payoff of the coalition formed by the players that adhere to the RFMO is given by:

\[
\pi = \frac{(pqk-c)r(1-b)}{(n-m)(m+2)^2 q}
\]  
(4.9)

The singleton nonmembers receive:

\[
\pi = \frac{(pqk-c)r(1-b)}{(m+2)^2 q}
\]  
(4.10)

From (4.9), it can be concluded that the payoff of the RFMO members decreases with the number of players, for a given number of nonmembers. Regarding the payoff of nonmembers, (4.10) indicates that it decreases with the number of coalitions.

Finally, under noncooperation all the players are nonmembers of the RFMO and behave as singletons. In the Nash equilibrium, the fishing effort and the payoff of each player are given, respectively, by:

\[
E = \frac{r}{(n+1)q}(1-b)
\]  
(4.11)

\[
\pi = \frac{(pqk-c)r(1-b)}{(n+1)^2 q}
\]  
(4.12)

The payoff of each singleton decreases with the number of players. Moreover, it converges to zero as the number becomes infinitely large.

Having determined the values of the per-member partition function of this game, the next step is to explore the properties of this function.
**Proposition 2.** The per-member partition function game presents positive externalities.\(^4\)

This proposition indicates that the merger of coalitions increases the payoff of players who belong to the other coalitions. Having established the presence of positive externalities in the game, its consequences will now be analyzed in terms of coalition structure stability and equilibrium. The following proposition addresses the coalition structure stand-alone stability for the present straddling stock fishery game.

**Proposition 3.** In a two-player game both the grand coalition and the coalition structure formed by singletons are stand-alone stable. In a game with three or more players the only stand-alone stable coalition structure is the one formed by singletons.

From this proposition it can be concluded that, aside from the unusual case of two players, no cooperative agreement is stand-alone stable. This is due to the presence of free rider incentives associated with positive externalities. The free rider behavior of nonmember fleets, which tends to occur in the presence of externalities, has been pointed out as one of the main factors behind the difficulties faced by RFMOs in the cooperative management of straddling fish stocks. A paradigmatic case is the Commission for the Conservation of Southern Bluefin Tuna.\(^5\) In order to protect itself against free riders, this RFMO has been trying to encourage nonmembers to adhere to the organization and has implemented a trade information scheme with the aim of deterring illegal, unreported, and unregulated fishing by effectively denying access to markets for the species.

Finally, the equilibrium of the game will be considered. This is a very relevant aspect since it is the expected scenario in the straddling fish stock fishery after all strategic adjustments have been made.

**Proposition 4.** In a two-player game the grand coalition, formed by the two players, is the Nash equilibrium coalition structure. If the number of players is three or more, the Nash equilibrium is the coalition structure in which all players act as singletons, that is, complete noncooperation.

Proposition 4 indicates that the cooperative management of a straddling fish stock under an RFMO is a very unlikely outcome. This result emphasizes the importance of dealing effectively with free rider behavior by nonmembers.

### 4.6 Application 2: North Atlantic bluefin tuna fishery

In this section the game in partition function form is applied to the eastern stock of the North Atlantic bluefin tuna. This straddling fish stock, whose management falls under the aegis of the International Commission for the Conservation of Atlantic Tuna (ICCAT), has been pointed out as one of the most typical cases of failure to implement a cooperative agreement (Pintassilgo 2003).
4.6.1 The fishery

The North Atlantic bluefin tuna is a large oceanic pelagic and also the largest of the tunas. Its normal fork length, in adult stage, is between 1.6 and 2.4 meters, but can reach more than 3 meters. Like many other tunas, the bluefin tend to be found in schools of similar-sized individuals. This species spawns in two main areas: the West Atlantic (Gulf of Mexico and Florida Straits) and the Mediterranean Sea (around the Balearic Islands and in the southern Tyrrhenian Sea). Based on the spawning areas, ICCAT defines two stocks for management purposes: the West Atlantic and the East Atlantic. Hereafter, the analysis is centered on the eastern stock, which is distributed roughly from the Canary Islands to southern Iceland and in all the Mediterranean Sea.

In the Northeast Atlantic and Mediterranean Sea, the bluefin tuna is harvested by a large number of fleets from European Union member coastal States (Cyprus, France, Greece, Italy, Malta, Portugal, Spain), other coastal States (Algeria, Croatia, Libya, Morocco, Turkey), and distant water fishing States (China, Japan, Republic of Korea, Taiwan, United States). A variety of fishing gears are used, including, purse seine, longline, trap, and baitboat. The different fishing gears target different quality and size specimens, which have different market values. Large-size and high-quality bluefin tunas are absorbed by the Japanese sashimi market, where prices are highest.

According to recent stock assessments, the eastern bluefin tuna stock is severely depleted and current reported catches (28,889 tonnes in 2004) cannot be sustained (ICCAT 2005). Furthermore, ICCAT suspects that there has been an increasing underreporting of catches over recent years. One of the main factors contributing to this situation is the high number of fleets involved in the fishery, both members and nonmembers of ICCAT. Another factor is the high price of the bluefin tuna in the Japanese market. This market has a strong and selective demand towards large-size and high-quality specimens, for which it is virtually the only consumer. The depletion of the southern bluefin tuna stock in the Pacific Ocean also contributes to the fishing pressure on the North Atlantic bluefin tuna.

4.6.2 Partition function game

Assume that all the countries participating in the bluefin tuna fishery in the East Atlantic and Mediterranean are represented in the RFMO, ICCAT, by one of the following players: European Union (EU), other coastal States (OCSs), and distant water fishing States (DWFSs). Consider the two-stage game framework presented in section 4.4. In the first stage, the coalition structure is determined by the players’ choice to join ICCAT or play outside as singletons. In the second stage, the coalitions choose their fishing strategy.

The optimal fishing strategy for the coalition formed by ICCAT members is assumed to be the one that maximizes the net present value of profits over a 25-year period, given the behavior of the nonmembers. Nonmembers are assumed to follow market behavior by adjusting effort.
The coalition strategies and payoffs were computed by using an age-structured, multigear bioeconomic model (Pintassilgo and Costa Duarte 2002). For all the coalition structures, a unique equilibrium payoff vector was obtained. The resulting payoff matrix (Pintassilgo 2003) is shown in Table 4.2. In representing the coalition structures, all the players that belong to the same coalition are placed within the same parentheses. As it is assumed that nonmembers act as singleton coalitions, all the coalitions with more than one member belong to ICCAT. Moreover, it is also assumed that ICCAT members will never be singletons, as no single player can gain by adopting a conservative strategy.

This game presents positive externality characteristics. In fact, Table 4.2 shows that when the EU joins the OCSs the payoff of the DWFSs increases from US$26.4 million to $837.6 million. A similar external effect occurs when the EU joins the DWFSs. The stability of the cooperative agreement will now be analyzed.

**Proposition 5.** There is no sharing rule that makes the cooperative agreement stand-alone stable.

This can easily be shown through proposition 1. The values of the singleton coalitions, resulting from unilateral deviations from the grand coalition, are −$13.8 million, $752.4 million, and $837.6 million for the EU, OCSs, and DWFSs, respectively. As the sum of these values ($1,576.2 million) exceeds the payoff of the grand coalition ($1,291.7 million), it can be concluded that there is no sharing rule that can make the grand coalition stand-alone stable. Since stand-alone stability is a necessary condition for a coalition structure to be a Nash equilibrium, the grand coalition cannot be a Nash equilibrium outcome of this game.

What is the Nash equilibrium of the game? It must be a stand-alone stable coalition structure. Using definition 4, it can be shown that there are only three coalition structures that follow this property: {(EU, OCSs), (DWFSs)}; {(EU, DWFSs), (OCSs)}; and {(EU), (OCSs), (DWFSs)}. Whether any is a Nash equilibrium depends on the particular sharing rule adopted for the division of the coalition payoffs. By using a variable sharing rule, endogenously determined, that can differ among coalition structures, Pintassilgo (2003) shows that there is no Nash equilibrium coalition structure for this game.

From these results, a successful cooperative agreement on the management of this fishery seems an unlikely outcome. However, as shown by Pintassilgo (2003), if DWFSs are not allowed to adopt free rider behavior then there are sharing rules that make the grand coalition stand-alone stable. Thus, the results indicate that legal restrictions, prohibiting fishing to fleets that do not follow the regulations set by RFMOs, are essential in order to sustain cooperative agreements.
4.7 Conclusion and policy implications

The management of straddling fish stocks has become a major international problem since the drafting of the United Nations Convention on the Law of the Sea (United Nations 1982). According to Munro (1999), the segment of the convention that addresses the management of these fishery resources “proved in retrospect to be seriously inadequate”. In 1995, the United Nations Fish Stocks Agreement was adopted in order to supplement the convention. However, some problems still remained to be solved, for example the threat to the cooperative management of RFMOs posed by prospective new members and nonmembers (Munro 2006). These problems are still clearly faced by such RFMOs as the Commission for the Conservation of Southern Bluefin Tuna and ICCAT.

Coalition games have been the main tool used by economists to address the management of straddling fish stocks. This chapter explores the potential of partition function games, a particular type of coalition game recently introduced into the fisheries literature. The main advantage of this approach, compared to traditional characteristic function games, is that it captures externalities among coalitions, which are generally present in straddling stock fishery games.

In the chapter, a game in partition function form is defined and applied in order to address the stability of cooperative agreements and the equilibrium coalition structures. The first application is a straddling stock fishery represented through the classical Gordon-Schaefer bioeconomic model. The results show that the game exhibits positive externalities. Moreover, in the case of three or more players, no cooperative agreement is stand-alone stable and the only Nash equilibrium coalition structure is the one formed by singletons. Thus, complete noncooperation is the most likely outcome. The second application is the bluefin tuna fishery in the Northeast Atlantic and Mediterranean Sea. In this application a fairly disaggregated bioeconomic model is used. It is also concluded that positive externalities are present and there is no sharing rule that can make the grand coalition stable.

Both games show very pessimistic prospects regarding the cooperative management of straddling fish stocks under RFMOs. This conclusion is in line with the results obtained by Yi (1997) for classical economic coalitions characterized by the presence of positive externalities, such as output cartels and coalitions formed to provide public goods. The author concludes that an open membership game rarely supports the grand coalition as a Nash equilibrium, and equilibrium coalition structures are often very fragmented.

According to the results obtained, the breakdown of cooperative agreements on straddling stock fisheries is a very likely scenario if countries can free ride on cooperative agreements. Thus, in order to protect cooperation, the legal regime must prevent those who engage in noncooperative behavior from having access to the resource. As Munro (2006) stresses, if the RFMO regime is to prosper, unregulated fishing by nonmembers must be eliminated. This is clearly on the agenda of the Food and Agriculture Organization of the United Nations (FAO) and is specifically
addressed in its International Plan of Action to Prevent, Deter, and Eliminate Illegal, Unreported, and Unregulated Fishing (FAO 2001). This is a voluntary instrument that recommends, among other measures, that States should develop and implement national plans of action to achieve the objectives of the International Plan of Action, and adopt trade restrictions on fish and fish products derived from illegal, unreported, and unregulated fishing, including import and export controls or prohibitions. According to the International Plan of Action, institutional and policy strengthening of RFMOs is a key element in addressing the problem of illegal, unreported, and unregulated fishing.

In 2003 a group of fisheries ministers and director-generals of international nongovernmental organizations created the High Seas Task Force with the aim of tackling “the root causes” of illegal, unreported, and unregulated fishing in the high seas. The final report (High Seas Task Force 2006) established a set of proposals intended to enhance enforcement, thereby increasing the risks to those engaged in illegal, unreported, and unregulated fishing operations, and making such fishing less profitable. Among the most prominent measures proposed by the High Seas Task Force are the improvement of the exchange of knowledge derived from monitoring, control, and surveillance activities, including through the development of a global information system on high seas fishing vessels; providing guidance to RFMOs in order to disseminate best practices in implementation of international fishery instruments; setting guidelines on flag State performance and measures in order to promote port State controls; and supporting developing countries in overcoming illegal, unreported, and unregulated fishing.

A key idea that emerges from this chapter is that the success of the management of straddling fish stocks under RFMOs, prescribed by the United Nations Fish Stock Agreement, is at serious risk unless the gaps in this document are filled with complementary measures that empower RFMOs to combat noncooperative behavior.
Appendix

Proof of proposition 2

Note that as all players are ex ante identical a coalition can be identified by its size. Thus, following Yi (1997), $C = \{S_1, S_2, \ldots, S_z\}$ is hereafter written as $C = \{n_1, n_2, \ldots, n_z\}$ where $n_i$ is the size of coalition $S_i$.

The presence of positive externalities in this game, according to definition 1, can be proved by showing that the merger of coalitions increases the payoff of all the players who belong to the other coalitions. Formally, this can be written as:

$$\pi(n_i; C) < \pi(n_i; C')$$ (4.A1)

Where $\{n_i\} \subset C$, $\{n_i\} \subset C'$, and $C \setminus \{n_i\}$ can be derived from $C \setminus \{n_i\}$ by merging coalitions in $C \setminus \{n_i\}$.

As it is assumed that all nonmembers of the RFMO behave as singletons, (4.A1) can be proven by showing that nonmembers are better off when additional players join the organization. Consider the general coalition structure $C = \{1, \ldots, 1, n-m\}$, $m \in \{1, \ldots, n-1\}$. Note that it includes all noncooperative coalition structures. Let $C' = \{1, \ldots, 1, n-m+l\}$, $l \in \{1, \ldots, m-1\}$. Thus, the condition (4.A1) can be written as:

$$\pi(1; \{1, \ldots, 1, n-m\}) < \pi(1; \{1, \ldots, 1, n-m+l\})$$ (4.A2)

Using the per-member partition function (equation (4.10)):  

$$\frac{(pqk-c) r (1-b)}{(m+2)^2 q} < \frac{(pqk-c) r (1-b)}{(m-l+2)^2 q}$$ (4.A3)

This yields:

$$\left(\frac{m-l+2}{m+2}\right)^2 < 1$$ (4.A4)

Proof of proposition 3

A two-player game will first be considered. The per-member payoff of the grand coalition and singletons, respectively, are given by:

$$\pi(2; \{2\}) = \frac{(pqk-c) r (1-b)}{8q}$$ (4.A5)
\[
\pi\left(1;\{1,1\}\right) = \frac{(pqk-c)r(1-b)}{9q}
\] (4.6)

The grand coalition is stand-alone stable as the per-member payoff exceeds that of noncooperation. In addition, the coalition structure formed by singletons is stand-alone stable by definition.

Take now the case of a game with three or more players. Considering first the grand coalition, it is assumed that this coalition structure is stand-alone stable. Using definition 4:

\[
\pi\left(n;\{n\}\right) \geq \pi\left(1;\{1,n-1\}\right)
\] (4.7)

Applying the per-member partition function (equations (4.7) and (4.10)):

\[
\frac{1}{n}(pqk-c)\frac{r(1-b)}{4q} \geq \frac{(pqk-c)r(1-b)}{9q}
\] (4.8)

Simplifying the inequality:

\[
n \leq \frac{9}{4}
\] (4.9)

Thus, the grand coalition is not stand-alone stable in a game with three or more players.

Consider now the coalition structures with at least two coalitions. This can be represented by \(C = \{1,\ldots,1,n-m\}, \ m \in \{1,\ldots,n-1\}\). Assume that \(C\) is stand-alone stable. Thus:

\[
\pi\left(n-m;\{1,\ldots,1,n-m\}\right) \geq \pi\left(1;\{1,\ldots,1,n-m-1\}\right)
\] (4.10)

Using the per-member partition function (equations (9) and (10)):

\[
\frac{(pqk-c)r(1-b)}{(n-m)(m+2)^2 q} \geq \frac{(pqk-c)r(1-b)}{(m+3)^2 q}
\] (4.11)

Rewriting the inequality:

\[
n - m \leq \left(\frac{m+3}{m+2}\right)^2
\] (4.12)

As \(1<\left(\frac{m+3}{m+2}\right)^2 < 2\), \(\forall m \in \{1,\ldots,n-1\}\), then \(n-m \leq 1\).

Hence, the only stand-alone stable coalition structure is the one formed by singletons.
Proof of proposition 4

Consider $n = 2$. From proposition 3 the grand coalition $C = \{2\}$ is stand-alone stable. Thus, $C = \{2\}$ is a Nash equilibrium coalition structure, because for the grand coalition there is equivalence between stand-alone stability and Nash equilibrium. The coalition structure $C = \{1,1\}$ is not a Nash equilibrium as each player becomes better off by joining the other and establishing a cooperative agreement. This is shown in the proof of proposition 3.

Consider $n \geq 3$. From proposition 3, $C = \{1,\ldots,1\}$ is the only stand-alone stable coalition structure and therefore the only candidate to be an equilibrium. $C = \{1,\ldots,1\}$ is a Nash equilibrium if and only if:

$$\pi\left(1;\{1,\ldots,1\}\right) \geq \pi\left(2;\{1,\ldots,1,2\}\right)$$  \hspace{1cm} (4.13)

Using the per-member partition function (equations (4.12) and (4.9)):

$$\frac{(pqk - c)r(1-b)}{(n+1)^2 q} \geq \frac{1}{2} \frac{(pqk - c)r(1-b)}{(n)^3 q}$$  \hspace{1cm} (4.14)

This yields:

$$\left(\frac{n}{n+1}\right)^2 \geq \frac{1}{2}$$  \hspace{1cm} (4.15)

This inequality is verified for $n \geq 3$. Thus, in the case of three or more players the coalition structure formed by singletons is the only Nash equilibrium of the game.
References


Table 4.1 Example of a characteristic function

<table>
<thead>
<tr>
<th>Coalition</th>
<th>Payoffs (net present value)$^\text{a}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norway, Iceland, EU (grand coalition)</td>
<td>6,800</td>
</tr>
<tr>
<td>Norway, Iceland</td>
<td>3,000</td>
</tr>
<tr>
<td>Norway, EU</td>
<td>2,800</td>
</tr>
<tr>
<td>Iceland, EU</td>
<td>2,700</td>
</tr>
<tr>
<td>Norway</td>
<td>750</td>
</tr>
<tr>
<td>Iceland</td>
<td>350</td>
</tr>
<tr>
<td>EU</td>
<td>140</td>
</tr>
</tbody>
</table>

$^\text{a}$ Approximate values in $10^6$ US$ (constant prices of 1998).

Table 4.2 Coalition payoffs for bluefin tuna fishery

<table>
<thead>
<tr>
<th>Coalition structure</th>
<th>Payoffs (net present value)$^\text{a}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>(EU, OCSs, DWFSs)</td>
<td>Total 1,291.7</td>
</tr>
<tr>
<td></td>
<td>ICCAT 1,291.7</td>
</tr>
<tr>
<td></td>
<td>EU —</td>
</tr>
<tr>
<td></td>
<td>OCS —</td>
</tr>
<tr>
<td></td>
<td>DWFS —</td>
</tr>
<tr>
<td>(EU, OCSs), (DWFSs)</td>
<td>991.8</td>
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<tr>
<td></td>
<td>154.2</td>
</tr>
<tr>
<td></td>
<td>837.6</td>
</tr>
<tr>
<td>(EU, DWFSs), (OCSs)</td>
<td>976.4</td>
</tr>
<tr>
<td></td>
<td>224.0</td>
</tr>
<tr>
<td></td>
<td>752.4</td>
</tr>
<tr>
<td>(OCS, DWFSs), (EU)$^\text{b}$</td>
<td>7.6</td>
</tr>
<tr>
<td></td>
<td>21.4</td>
</tr>
<tr>
<td></td>
<td>−13.8</td>
</tr>
<tr>
<td>(EU), (OCSs), (DWFSs)</td>
<td>7.6</td>
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<td></td>
<td>−13.8</td>
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<tr>
<td></td>
<td>−5.0</td>
</tr>
<tr>
<td></td>
<td>26.4</td>
</tr>
</tbody>
</table>

$^\text{a}$ Values in $10^6$ US$ (constant prices of 1995).

$^\text{b}$ If ICCAT is composed of OCSs and DWFSs there is no conservative strategy that can yield higher payoff for these players than in the case in which the three players act noncooperatively as singletons.
Notes

1 This broad definition includes what, in the terminology of the Food and Agriculture Organization of the United Nations, is called highly migratory fish stocks (mainly the six major tuna species). According to Munro (2006), there is no meaningful difference between straddling fish stocks and highly migratory fish stocks as far as economic analysis is concerned.

2 This is the most common abbreviated designation of the agreement and is used throughout the chapter. The full title is: Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 Relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks.

3 The assumption of ex ante symmetric players is dominant in the literature on partition function games (for example Yi 1997; Finus 2001). Allowing for asymmetric players raises significantly the level of complexity of the analysis because the results depend on the particular rule chosen to share the benefits from cooperation.

4 The proofs of this and the following propositions are provided in the Appendix.


6 Nonetheless, recent data on bluefin tuna releases and recoveries show significant mixing between the two stocks (ICCAT 2006).

7 This is a very common way to model noncooperative behavior in fisheries (for example Amundsen, Bjørndal, and Conrad 1995). One of its main advantages is that it can incorporate the natural restrictions on the effort adjustment.

8 The uniqueness of the equilibrium payoffs was one of the main factors behind the option for a particular modeling of nonmembers’ strategies rather than the use of the traditional Nash equilibrium. In fact, the complexity of the bioeconomic model raised the problem of nonuniqueness of the Nash equilibrium.