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The Blue Whiting Coalition Game

by

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Abstract

The current paper is an application of the analysis of coalition, in particular the partition function approach, to the North East Atlantic blue whiting fishery. In an Exclusive Membership/Coalition Unanimity game, a multi-agent, age-structured bioeconomic model simulates the behaviour of the agents in a setting where we allow for partial cooperation between the coastal states consisting of the European Union (EU), the Faroe Islands, Iceland, and Norway. We find that in a game played by the Exclusive Membership rules a coalition among all the coastal states is unstable, and cannot be a Nash equilibrium. Therefore, a coastal state agreement seems an unlikely outcome. However, under the more restricted Coalition Unanimity rules, fewer coalition structures are feasible, and the coastal state coalition becomes stable and the noncooperative coalition structure unstable.

Keywords: Straddling fish stocks, coalition approach, partition function, partial cooperation, coastal state agreement, Exclusive Membership/Coalition Unanimity game, blue whiting.

JEL Classification: Q22, Q28, C72.

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1 Introduction

The blue whiting (*Micromesistius poutassou*), a small gadoid, characterized as an oceanic semi-pelagic species living in the North East Atlantic, is one of the most abundant fish species in the Norwegian Sea. Being a straddling fish stock[1], migrating through many countries'exclusive economic zones (EEZs) as well as into international waters, it has been subjected to heavy exploitation by several European nations, especially since the late 1990s. However, due to the lack of international agreement for many years on how to divide a total allowable catch (TAC) among the nations, there was no agreed catch limit. This led to catches well above the advice of the International Council for the Exploration of Sea[2] (ICES), and thus the blue whiting fishery was not considered sustainable.

However, on 16 December 2005, after six years of negotiations, the coastal states consisting of the European Union (EU), the Faroe Islands, Iceland and Norway reached an agreement on the management and allocation of the blue whiting stock, limiting the catches of blue whiting to no more than 2 million tonnes for 2006 (Anon., 2005). A related regulation for international waters was adopted by the North East Atlantic Fisheries Commission[3] (NEAFC) for 2006. This agreement, renewed and ratified both for 2007 and 2008, can be seen as a coalition between the coastal states, while the fifth player,

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[1] Straddling fish stocks are a special category of internationally shared fishery resources that straddle exclusive economic zones (EZZ) where states have special rights over the exploration and use of marine resources, and adjacent high seas. These species, usually targeted by both coastal states and distant water fishing nations, became increasingly disputed after the establishment of exclusive economic zones by the United Nations Convention on the Law of the Sea (Anon., 1982).

[2] The International Council for the Exploration of the Sea, ICES, is an independent, scientific organization that advises regional fisheries organizations, the European Union, and other countries around the North Atlantic on the marine environment and its resources. ICES consists of three advisory committees; one on fisheries management (ACFM), one on marine environment (ACME), and one on ecosystems (ACE). The Advisory Committee on Fisheries Management collects scientific background material and offers annual advice on the catches of important fish species in the North Atlantic. Based on the advice given, the involved countries negotiate annual quotas and other management measures for the fish stocks.

[3] The North East Atlantic Fisheries Commission, NEAFC, is intended to serve as a forum for consultation, exchange of information on fish stocks and the management of these, and advise on the fisheries in the high seas areas mentioned in the convention on which the commission is based. Since most of the fisheries are within the jurisdiction of the coastal states, NEAFC has no real management responsibilities beyond the fraction of the fish stocks located within the high seas areas covered by the convention (Bjørndal, 2008).

Russia, not recognized as a coastal state by the others, is excluded from participating in a coastal state agreement on the management of this fishery.

The United Nations (Anon., 1995) calls for for the management of straddling/highly migratory fish stocks to be carried out through regional fisheries management organizations (RFMOs), to involve both the coastal states and the distant water fishing nations (DWFNs) (Bjørndal and Munro, 2003). Membership in an RFMO is open to any nation with real interest in the relevant fisheries, both coastal states and DWFNs. The term 'real interest' is not defined in the Fish Stocks Agreement, but can be taken to include nations currently engaged in exploitation of the fisheries; DWFNs which are not currently engaged in exploiting the fisheries, but which have done so in the past, and would like to re-enter the fisheries; DWFNs which have never exploited the fisheries, but which would like to enter. The blue whiting agreement does not follow this rule, as membership is for coastal states exclusively. Although membership in NEAFC is open to all nation with real interest in the blue whiting fishery, NEAFC adopts only management measures for the high seas based on what the coastal states set aside to be divided among all nations with real interest in the fishery, both coastal states and DWFNs.

Moreover, 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. The purpose of this paper is to investigate the incentives of the coastal states for forming coalitions in the first place, and, in the second, the stability of these coalitions after they have been formed. To do so we use the framework of economic coalition formation in the presence of externalities.

The current paper is an application of Pintassilgo's (2003) framework to the North East Atlantic blue whiting fishery. What separates it from Pintassilgo's work is the number of players, and thus the number of coalition structures, and instead of focusing on full cooperation in an Open Membership game, we consider the possibility of partial cooperation in an Exclusive Membership/Coalition Unanimity game. The Open Membership game is designed to describe an institutional environment in which an outsider can join an existing coalition if it is willing to abide by its rules, without further consent of its existing members. Under the Exclusive Membership game, on the other hand, consent of the existing members is required for an outsider to join a coalition. In the Coalition Unanimity game, the formation, expansion or merger of coalitions require the unanimous approval of the prospective members (Yi, 2003).

We find that in a game played by the Exclusive Membership rules, a coalition among all the coastal states is unstable and cannot be a Nash equilibrium. Therefore, a coastal state agreement seems an unlikely outcome in the first place. However, under the more restricted Coalition Unanimity rules, fewer coalition structures are feasible, and the coastal state coalition becomes stable and the noncooperative coalition structure unstable.

The paper is organized as follows. Section 2 describes the development of the blue whiting fishery and management. Section 3 outlines an age structured bioeconomic model of the fishery. In Section 4, we discuss the games and the rules of the game and define some fundamental concepts regarding stability. In Section 5, the game is applied to the blue whiting fishery. Finally, Section 6 concludes.

2 Development of the blue whiting fishery and its management

This section reviews the development of the blue whiting fishery from its beginning in the early 1970s until present. Furthermore, the process leading to the coastal state agreement on the management of the stock is discussed.

2.1 The blue whiting fishery

The blue whiting stock in the Northeast Atlantic migrating between the spawning areas west of the British Isles and south of the Faroe Islands and the feeding areas in Norwegian Sea straddles both high seas waters is, in principle, accessible to fishermen from every country, and the EEZs of several countries, the most important being the EU, the Faroe Islands, Iceland, and Norway. The map, Figure (1) names important places in relation to the blue whiting, and later Figure (3) shows the spawning areas and distribution pattern along with the migration routes. In the late 1960s and early 1970s, vessels from the Soviet Union started exploiting blue whiting in the Norwegian Sea (Bailey, 1982). The species was not listed separately in ICES's catch statistics until 1970, but for the first half of the 1970s this was somewhat incomplete (Monstad, 2004). Norway started experimental fishing with pelagic trawls in the spawning area in 1972. In the following years the technology of pelagic fishing developed rapidly, with larger vessels, more powerful engines and larger trawls fitted with acoustic devices, resulting in larger catches. From annual catches of 100 thousand tonnes in the first half of the 1970s, the landings more than doubled from year to year in the second half of the decade, reaching a maximum of more than 1.1 million tonnes in 1979-1980.

However, a few years later the landings were only half of this. After that the catches again started increasing and reached a new local maximum of about 900 thousand tonnes in 1986 (see Figure (2)). Then the fishery went into another decline, reaching its minimum of less than 400 thousand tonnes landed in 1991. Since then the landings steadily increased, until they suddenly increased from about 650 thousand tonnes in 1996 to 1.1 million tonnes the next year and continued increasing from then on more or less steadily to about 2.4 million tonnes in 2004 (ICES, 2005).

This rapid increase in the landings is linked to changes in the environmental conditions in the Northeast Atlantic, especially in the spawning period, described by Hátún et al. (2007), but also to favourable living conditions for the blue whiting throughout its

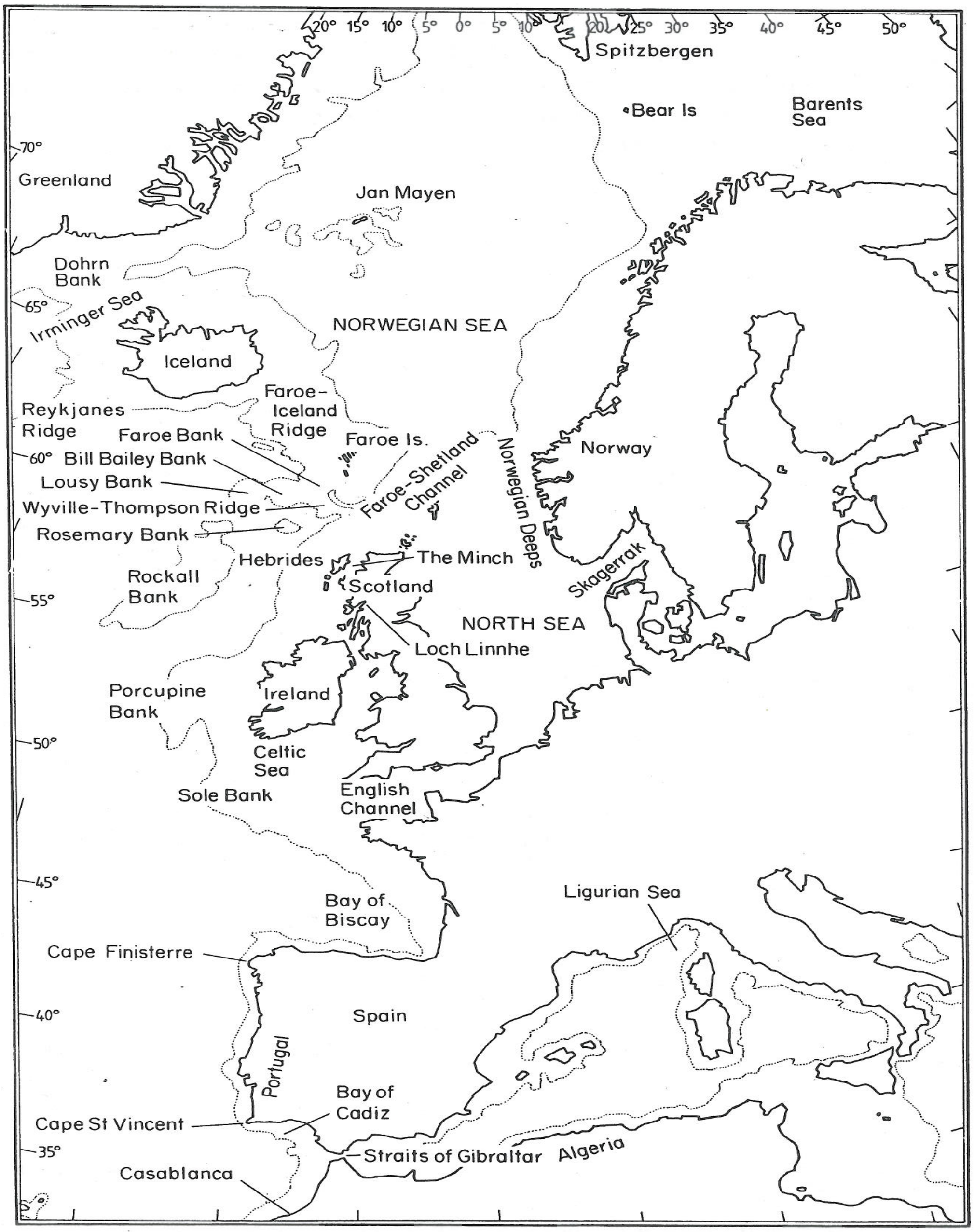

Figure 1: Map showing places referred to in the text (Bailey, 1982).

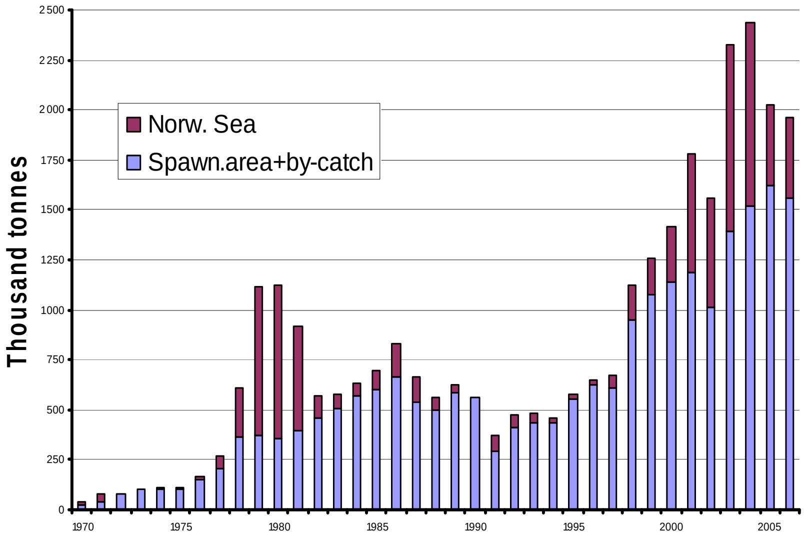

Figure 2: Landings from the main fisheries, 1970-2006 (adjusted from Monstad (2004)).

distribution area (Monstad, 2004). The explanation for the changes in distribution and abundance is not simple, and it is likely that a combination of several factors caused these changes.

Apart from the Russian Federation (former Soviet Union) and Norway, which developed the fishery, the blue whiting was mainly fished by vessels from the Faroe Islands and countries of the European Union. Only minor fishing was carried out by Icelandic vessels until the mid-1990s, when a new Icelandic fishery was initiated by a fleet of powerful vessels (Pálsson, 2005). As a consequence, the Icelandic catches of blue whiting increased rapidly, reaching 501 thousand tonnes in 2003.

To be able to fish blue whiting in the waters of other countries, the nations have negotiated bilateral quotas within the various zones[4]. Due to the lack of agreed sharing of the quota, the negotiations did not consider the recommended TAC. In addition, each country allowed for unlimited landings from its own as well as from international waters. As a result, the actual harvest in 2001 was in fact almost three times more than

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[4] This can be seen as a sort of what Munro (1979) called side-payments, or transfer payments in Clark (1990), page 158-164. Side-payments are essentially transfers, monetary or non-monetary, between and among players.

recommended by ICES (ICES, 2003).

2.2 The management

As the landings of blue whiting grew to significant quantities, it became clear that international agreement was needed on how to share this resource among the nations involved. The North East Atlantic Fisheries Commission, NEAFC, organized a series of meetings to this end, including workshops, discussions and negotiations. However, despite two years of such meetings in the early 1990s, when the matter was thoroughly dealt with, no agreement was reached on how to share the Total Allowable Catch (TAC), *i.e.*, the quota recommended by NEAFC on the basis of advice from ICES (Monstad, 2004).

The various countries involved have presented different ways to show the biological zonal attachment of blue whiting (Ekerhovd, 2003). Some countries use the concept of "biomass by time" within their zones (stock size within a zone multiplied with the duration of the stay) (Monstad, 2004), while others exclusively employ the catch statistics from the zone as the basic concept (Ekerhovd, 2003). A combination of these two methods is also used, and in some cases also the inclusion of factors such as economic dependence on the fishery. In the 2000-2001 coastal state meetings and in NEAFC (Ekerhovd, 2003), the relevant parties presented demands for their share along with what they thought the others' shares should be, resulting in a sum of national claims amounting to almost 180% of a possible TAC (Standal, 2006).

The process was put aside until 1998, when NEAFC set up a Working Group to deal with the issue and present suggestions for a solution. The Working Group consisted of representatives from the coastal states, *i.e.*, states that have the blue whiting stock occurring within their Exclusive Economic Zones (EEZ). These are the EU, Norway, Iceland, the Faroe Islands and Greenland (formally represented by Denmark). The Russian Federation (Russia) is also included, although not regarded as a coastal state by the others, but in any case it is a major participant in the blue whiting fisheries (Ekerhovd, 2003).

A great deal of work was carried out in this process. All the available relevant data were analyzed and used as a basis for discussion and negotiation. In spite of this and the urgent need for management measures to regulate the blue whiting fisheries, an agreement was not reach until late 2005.

However, in December 2005 the coastal states consisting of the EU, the Faroe Islands, Iceland, and Norway signed an agreement. The agreement, starting in 2006, includes a long term management strategy that implies annual reductions in the landings until the management goals are reached (Anon., 2006). This arrangement provided for catches in 2006 of 2 million tonnes, allocated as follows: the EU 30.5%, the Faroe Islands 26.125%, Norway 25.745% and Iceland 17.63%. Russia will be accommodated by transfers from some of the coastal states and additional catches in the NEAFC area (ICES, 2007).

An interesting aspect of this agreement is how the fishermen's organizations were instrumental in preparing the ground for the agreement. During the summer of 2005, prior to the coastal state agreement, various fishermen's organizations from the European Union, Iceland, and Norway negotiated and signed an agreement, similar to the one signed by officials from the coastal states later that year[5].

3 The bioeconomic model

In this section the three basic components of a bioeconomic model are discussed: the production function, the population dynamics, and the economic sub-model.

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[5] Source: A radio interview with the president of the Norwegian Fishing Vessel Owner's Association, Mr. Sigurd Teige, transmitted by the Norwegian Broadcasting Corporation (NRK), 16th December 2005.

3.1 The harvest production function

Our model encompasses age groups, aged from one-year-old recruits to fish of 10 years and older. The age groups are harvested simultaneously by applying a fleet-specific fishing mortality $f_{a,y,i}$ to all age groups. The catch rate for each fleet i is governed by two parameters, the effort, X_i, and the catchability coefficient, $q_{a,y}$, where a denotes the age group and y the fishing season. This is a version of the classical Schaefer (1957) production function, which assumes proportionality between effort and fishing mortality.

The selectivity of the pelagic trawls used in the blue whiting fishery is one for all age groups, meaning that the gear catches fish indiscriminately of size or age. The reason for this lack of age-specific escapement from the gear is that in the opening of the trawl, which covers a huge area of water, the mesh size is quite large, several meters in fact, while at the other end where the fish finally end up the mesh size is much smaller, about 50 mm. Furthermore there are one or two extra nets outside the fish end to prevent it from breaking due to the increased pressure generated when the swim bladder expands as the fish is forced to the surface. Thus, any age-specific catchabilty coefficient other than one indicates that the age group composition in the area where the fish is caught differs from the age group composition for the entire stock.

The abundance of each age group in landings from specific areas varies over time and is governed by many factors. The age distribution of the landings is not uniform across the age groups. Instead we stylize the catchability coefficients based on assumptions about the age distribution for each area that seems reasonable. In the first two quarters of the year, the stock is either migrating towards or already in the spawning areas. Therefore, the catchability coefficients for quarter one and two are set equal to the age specific proportion of the maturity ogive; that is, the age distribution of the harvest is equal to the age distribution in the spawning stock biomass. In the third quarter, the stock has finished spawning and has migrated to the feeding areas in the Norwegian Sea. As the older individuals start the migration earlier and travel farther than the younger ones (Bailey,

Table 1: Blue Whiting: Quarterly age specific selectivity in catches

Age	1	2	3	4	5	6	7	8	9	10+
First quarter	0.11	0.40	0.82	0.86	0.91	0.94	1.00	1.00	1.00	1.00
Second quarter	0.11	0.40	0.82	0.86	0.91	0.94	1.00	1.00	1.00	1.00
Third quarter	1.00	1.00	1.00	1.00	0.50	0.25	0.10	0.10	0.10	0.10
Fourth quarter	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

1982), they spread too much on their migration to be caught. Furthermore, younger individuals are reported being over-represented in the landings from the Norwegian Sea during summer (Heino, 2006). Therefore, the catchability coefficients of the third quarter are set to unity for the younger age groups, while held at a lower level for the older ones. In the fourth quarter we assume that the entire stock congregates before starting the migration back to the spawning grounds. This results in a uniform age distribution equal to one. The catchability coefficients are shown in Table (1). Note that the $q_{a,y}$s distribute the overall fishing effort across the different age groups.

3.2 Population dynamics

All age classes are subject to natural mortality, m, which is set to 0.2 for all age groups (ICES, 2007). It is assumed that only the older component of the population (from age class 7 on) is fully mature, whereas the younger age classes are only partially mature. The values for the maturity–ogive, given in Table (2), were estimated by the 1994 Blue Whiting Working Group (ICES, 1995). The estimate of the maturity ogive defines the proportion of the mature individuals in the age class as constant average, MO_a, for each age class. The annual spawning stock biomass is then given by

$$SSB_t = \sum_{a=1}^{10+} MO_a W_a N_{a,t}. \tag{1}$$

where W_a is the individual weight in kilograms at age a (ICES, 2007), shown in Table (2), and $N_{a,t}$ is number of individuals in age group a in year t.

Table 2: Blue whiting: proportion of maturation, weight at age, and numbers at age 2000-2006.

Age group	Proportion mature	Weight‡	Number of fish† 2000	2001	2002	2003	2004	2005	2006
1	0.11	0.049	39,743.1	62,497.4	45,631.2	48,220.4	33,551.6	24,040.7	1,141.0
2	0.40	0.075	16,963.6	30,681.3	47,661.7	35,374.2	33,551.6	25,544.5	18,435.0
3	0.82	0.102	16,123.1	11,916.0	21,291.1	33,737.2	25,251.3	25,948.5	18,369.9
4	0.86	0.125	12,150.7	9,579,3	6,932.3	12,869.4	2,069.6	14,962.8	15,955.9
5	0.91	0.147	3,813.6	6,318.9	4,784.9	3,602.6	6,808.6	10,467.8	7,862.8
6	0.94	0.168	909.8	1,985.9	3,153.4	2,463.2	1,835.3	3,252.9	5,220.1
7	1.00	0.185	435.0	409.8	875.3	1,427.3	1,141.5	761.2	1,440.2
8	1.00	0.200	207.4	196.0	180.6	396.2	661.6	473.5	337.0
9	1.00	0.222	138.7	93.4	86.4	81.8	183.6	274.4	209.6
10+	1.00	0.254	384.3	235.6	145.0	104.7	86.4	112.0	171.1

†Numbers in millions

‡Weights in kilogram per individual

The stock in the beginning of the first quarter each year is equal to the recruitment to the youngest cohort plus the fish that survived the last quarter the previous year.

The well known stock-recruitment relationships of Beverton-Holt (2) and Ricker (3) (Hillborn and Walters, 1992) turned out to be difficult to estimate, using the available data from 1981 to 2006 (ICES, 2007). That is, most of the parameters, shown in Tables (3) and (4), respectively, turned out insignificant, the estimations explained very little of the variation in the data, and the observations were serially correlated. Instead, a serially correlated stock-recruitment relationship, estimated on the recruitment from 1981 to 2006, reported in ICES (2007), was used in linking the number of recruits, R_t, to the previous year's recruitment, R_{t-1}. An explanation for this relationship is that the recruitment is mainly dependent on various environmental factors, such that a possible stock-recruitment relationship drowns in the noise. In addition, the serial correlation we found indicates that good, or bad environmental conditions occur at least two years in a row.

$$R_t = \frac{\alpha \times SSB_{t-1}}{\beta + SSB_{t-1}} \tag{2}$$

Table 3: Beverton-Holt stock-recruitment relationship, fitted to data from 1981-2006 (ICES, 2007).

Parameters*	α	β
Values	35329.5	3845.5
Standard Errors	34966.1	6551.5
$R^2_{adjusted}$	0.02	
Durbin-Watson test statistic	0.76	

*Estimated by a non-linear regression.

Table 4: Ricker stock-recruitment relationship, fitted to data from 1981-2006 (ICES, 2007).

Parameters	α	β
Values	1.999	17525.2
Standard Errors	0.423	15422.1*
$R^2_{adjusted}$	-0.0049	
Durbin-Watson test statistic	0.77	

*The standard error of β was estimated by a non-linear regression.

$$R_t = SSB_{t-1} \times \exp\left(\alpha(1 - SSB_{t-1}/\beta)\right) \tag{3}$$

Running this serially correlated recruitment process, starting from any initial recruitment level, the recruitment will converge to a certain recruitment level given the parameter values, and this level is independent of the fishing effort applied. This means that the steady state recruitment of the serially correlated recruitment process with the parameter values presented in Table (5) will be about 21.5 billion individuals entering the fishable stock in steady state. This recruitment level is relatively strong if we compare it with the average recruitment of the period 1981-1995, which was less than 10 billion recruits, but moderate if we compare it with the average recruitment of about 36 billion for the years 1996-2005. Such a strong and reliable recruitment would lead to an unrealistic and over-optimistic valuation of the stock and leave us with the impression that the stock can sustain a very high fishing effort indefinitely. In order to compensate for this and in spite of the fact that we were unable to establish any stock-recruitment relationship, we let the recruitment process be dependent on the spawning stock biomass, as follows.

In 1998, ICES's Advisory Committee on Fisheries Management (ACFM) defined limit and precautionary reference points for this stock as follows. B_{lim} (1.5 mill. t.), B_{pa} (2.25 mill. t.), F_{lim} (0.51) and F_{pa} (0.32) (ICES, 1998)[6]. The advice of ACFM in the following years has been given within a framework defined by these reference points (ICES, 2003).

Note that we do not treat the reference points as something that the countries have agreed upon (Lindroos, 2004b), but rather as a biological feature of the stock, and that fishing could continue even when the spawning stock is below B_{lim}.

As long as SSB is greater or equal to B_{pa} we let the recruitment follow the serially correlated process $R_t = \alpha + \beta \times R_{t-1}$. If SSB falls below B_{pa} but stays above B_{lim} the recruitment is fixed at α and 5113.6 million individuals are recruited annually. Further reduction of SSB below B_{lim} leads to partial recruitment failure, with recruitment dropping to only 500 million recruits annually. Hence

$$R_t = \begin{cases} 500, & if \quad SSB_{t-1} < B_{lim} \\ \alpha, & if \quad B_{lim} \leq SSB_{t-1} < B_{pa} \\ \alpha + \beta \times R_{t-1}, & otherwise. \end{cases} \tag{4}$$

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[6] The ICES approach is that for stocks and fisheries to be within safe biological limits, there should be a high probability that spawning stock biomass (SSB) is above a limit B_{lim}, where recruitment is impaired or the dynamics of the stock are unknown, and that fishing mortality is below a value F_{lim} that will drive the spawning stock to that biomass limit. Because of the occurrence of error in the annual estimation of F and SSB, operational reference points are required to take account of such error. ICES therefore defined the more conservative reference points B_{pa} and F_{pa} (the subscript pa stands for precautionary approach) as the operational thresholds. If a stock is estimated to be above B_{pa} there is a high probability that it will be above B_{lim} and similarly if F is estimated to be below F_{pa} there is a low probability that F is higher than F_{lim}. The reference values B_{lim} and F_{lim} are used for calculation purposes in order to arrive at B_{pa} and F_{pa}, the operational values that should have a high probability of being sustainable, based on the history of the fishery. Stocks above B_{pa} and below F_{pa} are considered to be inside safe biological limits. Stocks both below B_{pa} and above F_{pa} are considered to be outside safe biological limits, and stocks that are above F_{pa} but also above B_{pa} are considered to be harvested outside safe biological limits: in both cases action is required to bring them inside safe biological limits (ICES, 2002).

The parameter values in Equation (4) are shown in Table (5).

The empirical foundation for what will happen to the recruitment if the spawning stock biomass is severely reduced is weak. Over the period from 1981 to 2006 an SSB below B_{lim} has hardly been observed, was reported to be less than B_{pa} only a few times, and certainly did not collapse.

In 2001, ACFM stated that (our italics)

"the stock is considered to be outside safe biological limits. In recent years the stock has rapidly declined. SSB is estimated to have been at B_{pa} in 2000 and will be close to B_{lim} in 2001. Fishing mortality has increased from around the proposed F_{pa} in 1997, to well above F_{pa} in 1998 and 1999, and well above F_{lim} in 2000. Total landings in 2000 were 1.4 million t, far above the ICES recommended catch of 800 000 t. Landings in 2000 mainly consisted of the strong 1996 and 1997 year classes. The strength of incoming year classes is unknown. ICES recommends that the fishery in 2002 for blue whiting in all areas be closed until a rebuilding plan has been implemented" (ICES, 2003).

In 2002, ACFM stated that (our italics)

"the stock is harvested outside safe biological limits. The spawning stock biomass for 2001 at the spawning time (April) is inside safe biological limits while the SSB for 2002 is expected to be below B_{pa}. Fishing mortality has increased rapidly in recent years, and was estimated at 0.82 for 2001. Total landings in 2001 were almost 1.8 million t. The incoming year classes seem to be strong. ICES recommends that the fishing mortality be less than F_{pa} = 0.32, corresponding to landings of less than 600 000 t in 2003".

Implementation of a rebuilding plan, however, was no longer necessary since, according to the new assessment, the state of the stock was better than previously estimated.

The above illustrates the difficulty of predicting the development of a fish stock and also that the period we are dealing with can be regarded as extraordinary. In hindsight, and in spite of the high and increasing fishing mortality of this period, the SSB is estimated to have been about 4.3 million tonnes in 2000, about 4.6 million tonnes in 2001, and increasing until at least 2005. However, evidence from other heavily exploited fish

Table 5: Recruitment function parameters for the blue whiting, estimated over the period 1981-2006 (ICES, 2007).

Parameters	α	β
Values	5113.57	0.76
Standard Errors	3790.41	0.14
$R^2_{adjusted}$	0.56	
Durbin-Watson test statistic	1.51	

stocks suggests that sustained harvesting outside what is considered safe biological limits will eventually lead to recruitment failure and stock collapse, although under favourable environmental conditions it may take some time for this to become evident. Hence, we have decided to follow the biologists in assuming that a low SSB and a high fishing mortality indicates that the stock is harvested outside safe biological limits that will eventually end in a recruitment failure.

Harvest within a certain year is modelled sequentially. That is, the blue whiting stock migrates through different waters during a year, see the map in Figure (3) (cf. Figure (1)), and is available for harvest in different proportions in the EEZs and the high seas areas in the North East Atlantic, depending on the season. The model is divided into quarterly seasons, and Table (6) shows the quarterly shares, $S_{i,y}$ (where $i = EU, FO, IS, NO, NEAFC$ and y denotes the season), of the stock attached to the different waters.

In the first quarter of the year, we assume that the blue whiting stock has migrated to waters west of Ireland and Great Britain and that 50% of the stock is available for harvest by vessels from the member countries of the European Union within the EEZs around Ireland and Great Britain. Meanwhile, fishing vessels from non-EU member countries, as well as EU vessels, can harvest on the remaining stock biomass in international waters beyond the EU's EEZ.

In the second quarter, the blue whiting population has migrated to the spawning grounds located within the EEZs of the EU and the Faroe Islands and is assumed to be

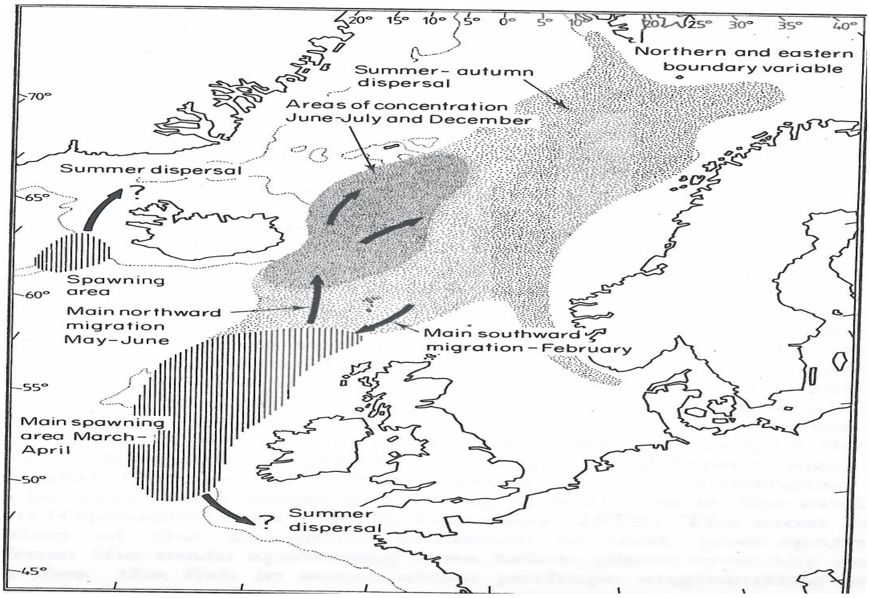

Figure 3: Map summarizing the migration pattern and areas of concentration of adult blue whiting (Bailey, 1982).

equally divided between the two zones and only available for harvesting by vessels from the EU and the Faroe Islands. Meanwhile, the vessels from the other blue whiting fishing nations are excluded from participating in the fishery on the spawning grounds, which are assumed to be within the EEZs of the EU and the Faroe Islands.

In the third quarter, the remaining part of the stock spreads out into the feeding areas in the Norwegian Sea, and is thus available for harvesting in the EEZs of Norway, Iceland, and the Faroe Islands, while the EU and Russia only harvest the blue whiting in the high seas areas. We assume that most of the stock (90%) has left Faroes waters and is distributed with 25% in both international waters and the Icelandic EEZ. The remaining 40% is found in Norwegian waters. The reason for assuming that the stock is more concentrated in Norwegian waters is that Norway has, or claims, jurisdiction not only over the 200 nautical miles zone surrounding mainland Norway, but also over the 200 nm zone around the island Jan Mayen and over the fishery protection zone around the Svaldbard (Spitzbergen) archipelago. Combined, these waters cover a significant part of the blue whiting summer feeding area.

Table 6: Quarterly zonal attachment of the blue whiting stock in %

	First quarter	Second quarter	Third quarter	Fourth quarter
NEAFC RA	50		25	20
European Community	50	50		
Faroe Islands		50	10	25
Iceland			25	20
Norway			40	35

In the fourth and last quarter, the blue whiting is still present in the Norwegian Sea, but the stock is now distributed with 20% in the EEZ of Iceland and the high seas areas in the Norwegian Sea. The Faroese share of the stock has risen to 25%, while Norway's share has declined by five percentage points to 35%. The EU and Russia still have to fish on the high seas.

The numbers of fish at the beginning of a season that have survived last quarter's harvest and avoided death by natural causes, are given as (dropping the year subscript t)

$$\begin{aligned} N_{a,y} =& N_{a,y-1}\Bigg\{ S_{NEAFC,y-1} e^{-[m/4+q_{a,y-1}\sum_i X_i]} \\ &+ \sum_j S_{j,y-1} e^{-[m/4+q_{a,y-1}X_j]} \Bigg\}, \end{aligned} \tag{5}$$

where $i = EU, FO, IS, NO, RU$, and $j = EU, FO, IS, NO$.

Ignoring the possibility of side-payments (Munro, 1979), *i.e.*, unilateral quota swapping that allows foreign vessels to fish blue whiting inside other nations' exclusive economic zones (EEZs), we assume that the vessels fish in their respective EEZs and in the high seas areas, the North East Atlantic Fisheries Commission Regulatory Area, referred to as NEAFC (RA). Although, the unilateral quota swapping is not insignificant, and some nations fish an extensive part of their blue whiting landings in other waters

Table 7: Validation of the model.[†]

Year		Fleets					Total
		EU	FO	IS	NO	RU	
2000	Observed	86,240	138,473	260,184	552,612	211,541	1,249,050
	Fitted	86,239.7	138,472.8	260,183.0	552,611.7	211,540.8	1,249,048.0
	Effort	0.0103	0.0189	0.0364	0.0570	0.0473	
2001	Observed	157,575	189,950	365,099	496,980	315,586	1,525,190
	Fitted	157,574.2	189,949.5	365,098.5	496,979.5	315,585.8	1,525,187.0
	Effort	0.0167	0.0226	0.0429	0.0465	0.0607	
2002	Observed	180,069	205,420	286,420	558,068	298,367	1,528,344
	Fitted	180,068.5	205,419.5	286,418.9	558,067.8	298,367.1	1,528,342.0
	Effort	0.0160	0.0208	0.0291	0.0428	0.0489	
2003	Observed	307,832	335,504	501,494	851,396	360,160	2,356,386
	Fitted	307,831.0	335,503.8	501,493.4	851,395.7	360,160.3	2,356,384.0
	Effort	0.0239	0.0315	0.0465	0.0606	0.0533	
2004	Observed	358,517	322,319	422,078	957,734	346,762	2,407,410
	Fitted	358,516.0	322,318.4	422,076.9	957,733.3	346,761.6	2,404,406.0
	Effort	0.0268	0.0298	0.0393	0.0650	0.0506	
2005	Observed	376,308	265,574	265,886	738,599	332,240	1,978,607
	Fitted	376,307.3	265,573.5	265,885.2	738,597.9	332,239.5	1,978,603.0
	Effort	0.0304	0.0271	0.0282	0.0563	0.0539	
2006	Observed	293,730	327,421	314,769	642,452	329,454	1,907,826
	Fitted	293,729.5	327,420.6	314,768.3	642,451.4	329,454.0	1,907,824.0
	Effort	0.0289	0.0435	0.0452	0.0702	0.0697	

[†] Landings in tonnes.

than their own EEZs, the exchange has a tendency to go both ways so that the net effect evens out. Moreover, some 25-35% of the total landings of blue whiting in the period 200-2006 were caught in the NEAFC regulatory areas.

In order to validate the model and the parameter values presented in Tables (1), (2) and (6) we have tried to reproduce the national landings between 2000 and 2006, fitting the model to the observed landings by choosing the effort such that it minimizes the error squared. The results of this fit are presented in Table (7).

The fleets are allowed to fish within their nation's EEZ and in international waters. The efforts presented in Table (7) are held fixed within a specific year. As we can see, the differences between the observed landings and the harvests of the model are small, suggesting that the model using the listed parameter values is able to give a fairly accurate description of the fishery.

3.3 Economic model

ICES's ACFM Northern pelagic and blue whiting working group has conducted surveys, and published reports on the development of the blue whiting stock. Data available on the economics of the blue whiting fishery, on the other hand, is scarce, not at all structured, disperse and not consistent. The exception is the Norwegian revenue surveys, collected by the Directorate of Fisheries 1991-2004, where data from vessels targeting blue whiting along with several other important species are published (Ekerhovd, 2007). Due to the severe data constraints, we build the model and determine intuitively those parameters that cannot be estimated for lack of data. It is then possible to test the sensitivity of the objective function to changes in these parameters.

The profits earned by the different national fleets during a quarter of the year are as follows (dropping the year subscript t)

$$\begin{aligned}\pi_{i,y} =& pX_i \sum_{a=1}^{10+} q_{a,y} N_{a,y} w_a \left[\frac{S_{j,y}(1 - e^{-[m/4+q_{a,y}X_i]})}{m/4 + q_{a,y}X_i} + \frac{S_{NEAFC,y}(1 - e^{-[m/4+q_{a,y}\sum_i X_i]})}{m/4 + q_{a,y}\sum_i X_i} \right] \\ &- c_i X_i,\end{aligned} \tag{6}$$

where $i = EU, FO, IS, NO, RU$, and $j = EU, FO, IS, NO$.

Here X is purely notational, and the only modes of cooperation observed are where the countries compete against each other, *i.e.*, no cooperation at all, or full cooperation among the coastal states with Russia as a nonmember. However, there are several possible ways in which the countries can engage in partial cooperation that are not observed in real life. Nevertheless, these intermediate, and hypothetical levels of cooperation are important in finding the Nash equilibrium in a coalition game. Hence, to be able to proceed with this analysis, we need a consistent method of finding cost parameters for

Table 8: Cost parameters.

	Coalition cost parametre[†]									
Coalition Structure	CS	3CS	2CS	2CS	EU	FO	IS	NO	RU	X^{∞}
Sole-Owner	6735									0.13010
(EU,FO,IS,NO),(RU)	6585								1565	0.10630
(EU,FO,IS),(NO),(RU)		5903						3156	1770	0.08994
(EU,FO,NO),(IS),(RU)		6540					2586		1770	0.08994
(EU,IS,NO),(FO),(RU)		6064				3301			1770	0.08994
(FO,IS,NO),(EU),(RU)		5845			3270				1770	0.08994
(EU,FO),(IS),(NO),(RU)			4745				2695	3335	1735	0.07855
(EU,IS),(FO),(NO),(RU)			3676			2673		2869	1050	0.07060
(EU,NO),(FO),(IS),(RU)			4222			2673	2322		1050	0.07060
(FO,IS),(EU),(NO),(RU)			3493		2856			2869	1502	0.07060
(FO,NO),(EU),(IS),(RU)			4039		2856		2322		1502	0.07060
(IS,NO),(EU),(FO),(RU)			4296		3478	3133			1736	0.07855
(EU,FO),(IS,NO),(RU)			5046	4320					1770	0.08994
(EU,IS),(FO,NO),(RU)			4470	4895					1770	0.08994
(EU,NO),(FO,IS),(RU)			5107	4258					1770	0.08994
(EU),(FO),(IS),(NO),(RU)					3451	3096	2673	3314	1710	0.06987

[†] The costs are in million NOK.

every coalition under every imaginable coalition structure; as follows: Assuming that all fleets apply an effort, X^{∞}, that results in a minimum recruitment such that the minimum stock level is reached after 35 years. Having done this, we found cost parameters such that the sum of the present value of the costs equals the sum of the present value of the revenue. Since most vessels also have important activities targeting other species, fixed costs were not considered. A criticism of this procedure is that in open access, the stock will be fished down to a break-even level in the long run, but in the meantime there will be some profit due to a large stock. However, we let this profit be absorbed by the costs. Our goal here is not to find the inter-marginal profit of open access, but intuitively determine those coefficients that cannot be estimated for lack of data. When calibrating the cost parameters we use the age composition of 2000 as initial stock. The resulting cost parameters are shown in Table (8).

4 The Game

A straddling stock fishery usually involves many countries and fleets. 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 mutual agreement on the particular fishery.

Three types of coalition scenarios may result. If all parties concerned sign the agreement, the situation is denoted full cooperation, and a grand coalition is said to be formed. If some countries are left outside the agreement, the situation is denoted partial cooperation, and the 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 benefits 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 behaviour of nonmembers. The assumption made in this paper is that nonmembers of the grand coalition can either form smaller coalitions, or act as singleton, and adopt individually best-response strategies against other coalitions. This results in a Nash equilibrium between the coalitions.

Characteristic function games have been applied to straddling stock fisheries since the late 1990s (Kaitala and Lindroos, 1998; Arnason *et al.*, 2001; Lindroos and Kaitala, 2001; Lindroos 2004a; Burton, 2003; Duarte *et al.*, 2000; Brasão *et al.*, 2001). Nonetheless, 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.

According to Yi (1997), the formation of economic coalitions with externalities opened a new strand of literature on noncooperative game theory. Most studies are centred on finding the equilibrium number and size of coalitions and share a common two-stage game framework (Pintassilgo and Lindroos, 2008). In the first stage players form coalitions, whereas in the second stage coalitions compete against each other. The coalition payoffs are represented by a partition function. This function assigns a value to each coalition as a function of the entire coalition structure. Therefore, it captures the externalities across coalitions that are assumed to be absent in the characteristic function.

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

In the second stage, it is assumed that the members of the coalition act cooperatively, by choosing a fishing strategy that maximizes the net present value for the coalition, given the strategies of the outsiders. The outsiders, or all players in the case of no cooperation, choose the strategy that maximizes their own individual payoffs given the behaviour of the other players. This noncooperative behaviour leads to a noncooperative solution for each coalition structure, which is assumed to be unique. Thus, the coalition payoffs in the second stage can be defined as a partition function. This function assigns a value to each coalition which depends on the entire coalition structure.

4.1 The Rules of the Game

Consider a two-stage game and a finite numbers of players. In the first stage each player has to decide whether to form a coalition with other players or act individually as a singleton.

Two types of games, known from the literature on coalition formation, that could possibly be used in the blue whiting fishery case are The Exclusive Membership game and the Coalition Unanimity game (Yi, 2003). Under the Exclusive Membership[7] game, consent of the existing members is required for an outsider to join a coalition. For example, Russia is not recognized as a coastal state by the other blue whiting fishing nations and, thus, excluded from the coalition.

Each player simultaneously announces a list of players (including itself) with whom it is willing to form a coalition. The players that announce exactly the same list of nations belong to the same coalition. Formally, player i's strategy α^i [8] is to choose a set of players S^i (itself included), a subset of $S \equiv \{P_1, P_2, ..., P_N\}$. Given the players' announcements $\alpha \equiv (S^1, S^2, ..., S^N)$, the resulting coalition structure is $C = \{B_1, B_2, ..., B_m\}$, where players i and j belong to the same coalition B_k if and only if $S^i = S^j$, that is, they choose exactly the same list of players (m is the number of different lists chosen by the players).

In the Coalition Unanimity game, on the other hand, the formation, expansion or merger of coalitions require the unanimous approval of the prospective members. In the Exclusive Membership game, described above, when some members of of a coalition leave to join and/or form other coalitions, the remaining members stay on as a smaller coalition. Under the Coalition Unanimity rule, however, a members's departure results in the dissolution of the coalition.

As in the Exclusive Membership game, each player announces a subset of players (including itself) with which it is willing to form a coalition, but a coalition forms only upon unanimous approval by the prospective members. Formally, for each n-tuple of strategies $\alpha = (S^1, S^2, ..., S^N)$, the resulting coalition structure is $C = \{B_1, B_2, ..., B_m\}$ where $P_i \in B_k (= S_i)$ if and only if $S^i = S^j$ for all $P_j \in S^i$, and $P_i \in \{P_i\}$ otherwise. For example, suppose that there are four players and that $\alpha = (\{P_1, P_2, P_3\}, \{P_1, P_2, P_3\}, \{P_3\}, \{P_3, P_4\})$. In the Exclusive Membership game, P_1 and P_2 form a coalition, because they announce the same list of players. But in

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[7] Hart and Kurz's (1983) original name is "game Δ". In order to contrast this game to the Open Membership game, this game is renamed the Exclusive Membership game (Yi, 2003).

[8] Do not mistake this with the α of the recruitment process.

the Coalition Unanimity game, they stay as singleton coalitions, because P_3 does not participate in their coalition. Hence, the resulting coalition structure is $\{1, 1, 1, 1\}$[9]. In the Exclusive Membership game, P_2's announcement of $\{P_1, P_2, P_3\}$ signals his willingness to form a coalition with any subset of players who are on his list. In the Coalition Unanimity game, on the other hand, the same announcement by P_2 means that he will form a coalition with the players on his list if and only if all prospective members participate in the coalition. In other words, upon the departure of some members of a coalition, the remaining stay as a smaller coalition in the Exclusive Membership game, but they dissolve their coalition and become singleton coalitions in the Coalition Unanimity game.

The five players of the blue whiting fishery game, the European Union (EU), the Faroe Islands (FO), Iceland (IS), Norway (NO), and the Russian Federation (RU), made the following announcements:

$$\begin{aligned}\alpha =&(\{EU, FO, IS, NO\}, \{EU, FO, IS, NO\}, \{EU, FO, IS, NO\},\\ &\{EU, FO, IS, NO\}, \{EU, FO, IS, NO, RU\}).\end{aligned}$$

Since the coastal states consisting of the EU, the Faroe Islands, Iceland, and Norway, choose exactly the same list of players, they belong to the same coalition. Russia, on the other hand, forms a one-player coalition, because it announced a list different from the others.

The resulting coalition structure is independent of whether the game is played by the Exclusive Membership rule or Coalition Unanimity rule. But when it comes to the stability of the coalition the distinction might be important. In the Exclusive Membership game, the players can leave the coastal state coalition unilaterally to form a singleton while the other coastal states stay on as a smaller coalition. In the presence of positive

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[9] In this case the players are symmetric, that is, all players have the same strategy sets and payoff functions; and the identities of the players do not matter so that the interchange of players i's and j's strategies results in the interchange of player i's and j's payoffs but does not affect other players' payoffs. Thus, a coalition is identified by its size.

externalities, players might find it profitable to leave the coalition and act as singletons, provided the other coastal states continue to cooperate. However, if the result of one player leaving the coastal state coalition is the end of cooperation and all players revert to singleton behaviour, the game is played by the Coalition Unanimity rule, and the only way for the coastal states to realize the gains of cooperation is to engage in it.

Notice that although Russia is not accepted as a coastal state by the others, it might also benefit from the positive externalities created by the formation of a coalition among the coastal states.

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 an Exclusive Membership game or a Coalition Unanimity game of coalition formation.

It is not clear whether it is the Exclusive Membership game or the Coalition Unanimity game that fits the blue whiting case best. One could argue that a coalition among the remaining coastal states would continue if one of them decided to leave. On the other hand, there is little evidence of the players forming sub-coalitions before a coastal state agreement was reached after several years of negotiations.

The coalition is said to be stable if there is no player that finds it optimal to join the coalition (external stability) and if no player within the coalition finds it optimal to leave the coalition (internal stability). When determining the stability properties of the grand coalition it is sufficient to check for internal stability if there are no potential entrants in the fishery (Lindroos *et al.*, 2007).

4.2 Stability of the Coalition Structures

Let us first define some fundamentals concepts, following Pintassilgo (2003), starting with the characteristic function.

Definition 1.

Let $N = \{1, 2, ..., n\}$ be a set of players. Any subset of N is a *coalition* and 2^N denotes the collection of its 2^n coalitions. A *coalition* function (or *characteristic* function) $V : 2^N \rightarrow R$ is a real-valued function which assigns a value $V(S)$ to each coalition S and which satisfies $V(\varnothing) = 0$.

Let us continue the definitions with the notions of coalition structure and partition function.

Definition 2.

A *coalition structure* $C = \{S_1, S_2, ..., S_m\}$ is a partition of the set of players $N = \{1, 2, ..., n\} : S_i \cap S_j = \varnothing$ for $i \neq j$ and $\cup_{i=1}^{m} S_i = N$.

Definition 3.

Let Ω be the set of all partitions of N. A game in *partition function* form specifies a coalition value, $V(S, C)$, for every partition C in Ω and every coalition S which is an element of C.

Let us now turn to the analysis of the presence of externalities among coalitions, in our game. Externalities are present, in a game in coalition form, if there is at least one coalition whose value depends on the overall coalition structure. Formally this can be defined as follows:

Definition 4.

Externalities are present, in a game in coalition form, if and only if the following condition is verified:

$$\exists S, C \quad and \quad C' \in \Omega :$$

$$S \subset C \quad and \quad S \subset C', \quad C \neq C' \quad and \quad V(S,C) \neq V(S,C')$$

If the change in the coalition structure corresponds to a concentration, i.e., the final structure can be obtained from the initial one only by merging existing coalitions, then the externality on a nonmerging coalition can be qualified as positive (negative) if it increases (decreases) the coalition value.

Well-known economic coalitions, such as output cartels in oligopoly and coalitions formed to provide public goods, tend to create positive externalities on nonmember players. In the management of straddling fish stocks, positive externalities are also expected to be present. In fact, as the members of the regional fishery organizations tend to adopt conservative strategies, a nonmember player is typically better off the greater the number of players that join the organization. In this scenario, an interesting point to explore is the impact of externalities on the stability of coastal states agreements.

Let us continue by addressing the notion of stability. As the merger of players into coalitions tends to create positive external effects on the 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, namely in characterizing equilibrium coalition structures. This concept is defined as follows:

Definition 5.

A coalition structure $C = \{S_1, S_2, ..., S_m\}$ is *stand alone stable* if and only if

$$V(S_k, C) \geq \sum_{i=1}^{n} V_i(S^i, C_i), \qquad \forall i \in S_k, \quad \forall k, k = 1, ..., m$$

where

S^i represents a singleton coalition formed only by player i, and

$C_i = (C \backslash S_k) \cup (S_k \backslash S^i) \cup (S^i)$, stands for a coalition structure formed from the original coalition structure (C), in which coalition S_k is divided into two sub-coalitions: $(S_k \backslash S^i)$ and (S^i). In other words, player i leaves coalition S_k and forms a singleton coalition, *ceteris paribus.*

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

5 The Results.

This section presents the results of simulating the development of the blue whiting fishery under different coalition structures. After the presentation of the payoffs a partition function is defined and the results are discussed in the context of the Exclusive Membership game. Finally, following the sensitivity analysis, the results are discussed in the Coalition Unanimity game context.

Table (9) presents the payoffs in this game from applying the constant fishing effort strategy[10] over a 35-year period starting in 2006, computing Nash equilibria for all the coalition structures[11]. The price per kilogram of fish is NOK 0.8, and the discount rate is set to 5%. The profit-income ratios using the cost parameters in Table (8) are as follows. For the coalition structure where all players act as singletons the ratios are 17%, 10%, 12%, 12%, and 15% for the EU, Faroe Islands, Iceland, Norway[12] and Russia, respectively.

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[10] A constant effort strategy corresponds to a variable catch strategy, where catch depends positively on the stock level. This type of strategy is especially relevant when there are significant costs of effort adjustment, as in the presence of high fixed costs or difficulties in transferring fishing effort between different fisheries.

[11] Lindroos and Kaitala (2001) were the first to compute Nash equilibria for coalition fisheries games.

[12] The cost-price ratio in the Norwegian blue whiting fishery 1998 - 2001 was estimated to be in the

The coastal state coalition has a profit-income ratio of 38%, while for Russia it is 37%. Under sole-owner management, however, the profits make up about 54% of the gross income from the fishery.

For the coalition structures where two players merge into a coalition while the others continue as singletons we were unable to obtain unique equilibrium payoff vectors. This results in a large numbers of Nash equilibria, where the number of strategy combinations depends on how the model is discretized and is restricted by computational capacity and time. The reason for this is that the complexity of the bioeconomic model raises the problem nonuniqueness of the Nash equilibrium (Lindroos and Kaitala, 2001). In order to overcome the problems of nonuniqueness we assume that for a two-player coalition to form, leaving the other countries as singletons, the merging countries have to gain by such a coalition structure otherwise they would be as least as well off as singletons, so the other countries will be initially caught in a situation where the two-player coalition chooses the Nash equilibrium strategy that maximizes its own payoff. Faced with this, we assume the best response of the ones remaining as singletons is to choose the strategy that maximizes its own payoff given the strategy of the two-player coalition assuming that their fellow singleton players do the same. In Table (9) we therefore present the payoffs for these cases, along with the mean, maximum and minimum payoffs for each coalition of the coalition structures with nonunique payoff vectors. However, it is not guaranteed that a coalition consisting of two players would be able to act as as leader in all circumstances. As shown in Table (9), under some coalition structures the spread of the payoffs is considerable, so it would be difficult to tell what would be the actual outcome if a {2,1,1,1} coalition structure were to form. Although not ideal, we use this as an equilibrium selection criterion, and treat the solution as if it were unique.

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range from 0.087 in 1998, to 0.181 in 2000, averaging 0.148 (Ekerhovd, 2003).

Table 9: Blue Whiting Game - Payoffs.[†]

		Payoffs - Net Present Value[‡]								
Coalition Structure	Total	CS	3CS	2CS	2CS	EU	FO	IS	NO	RU
Sole-Owner	7871									
(EU,FO,IS,NO),(RU)	6587	3495								3093
(EU,FO,IS),(NO),(RU)	4465		1710						1306	1449
(EU,FO,NO),(IS),(RU)	4384		1696					1317		1371
(EU,IS,NO),(FO),(RU)	4654		1513				1645			1496
(FO,IS,NO),(EU),(RU)	4447		1370			1542				1536
(EU,FO),(IS),(NO),(RU)	2223			798				469	279	677
mean	2120			732				446	398	545
max				798				510	490	677
min				616				356	279	433
(EU,IS),(FO),(NO),(RU)	3199			1861			987		169	182
mean	3703			793			803		623	1484
max				1861			2068		1403	2972
min				121			49		153	180
(EU,NO),(FO),(IS),(RU)	3327			1623			1016	150		537
mean	3683			737			841	605		1501
max				1623			2068	1405		2872
min				143			46	153		176
(FO,IS),(EU),(NO),(RU)	2826			1862		67			681	216
mean	2603			788		307			702	807
max				1862		730			1255	1584
min				223		33			308	195
(FO,NO),(EU),(IS),(RU)	2510			1432		416		284		378
mean	2543			776		339		675		753
max				1432		856		1189		1387
min				282		34		252		195
(IS,NO),(EU),(FO),(RU)	3725			1093		1770	55			806
mean	2761			484		959	766			553
max				1093		1770	1137			806
min				148		337	55			438
(EU,FO),(IS,NO),(RU)	4612			1843	1256					1513
(EU,IS),(FO,NO),(RU)	4642			1644	1486					1513
(EU,NO),(FO,IS),(RU)	4483			1579	1516					1389
(EU),(FO),(IS),(NO),(RU)	1997	1558[*]				606	331	351	271	439

[†] The initial stock as it was in 2006.

[‡] Values of NPV in million NOK.

[*] The sum of payoffs from the coastal states acting as singletons.

5.1 Partition function

From the payoffs presented in Table (9), it is now possible to define a partition function. Let $V^*(C_{CS}, C_{CS})$ denote the net return to be shared by the four members when the coastal state coalition is formed. This is equal to the present value of the coastal state cooperative strategy less the sum of the threat points of each member.

$$V^*(C_{CS}, C_{CS}) = 3,494.8 - 1,558.3 = NOK \quad 1,936.5 \quad million \tag{7}$$

Let the value of the players that belong to the same coalition equal the coalition value.

$$V(S^i, C_i) = \frac{\pi(S, C) - \sum_{i \in S} \pi(S^i, C_T)}{V^*(C_{CS}, C_{CS})},$$

where the notation stands for:

$\pi(S, C)$ - payoff of coalition S under coalition structure C;

$S^i = \{i\}$ and $C_T = \cup_{i=1}^{n} S^i$,

i.e., S^i stands for a singleton coalition formed only by player i and C_T for the coalition structure in which all players act as singletons.

Therefore, $\pi(S^i, C_T)$ is the threat point of player i.

Let us also assume that player i will only be a member of coalition S if it receives a nonnegative normalized value, i.e., its final payoff must not fall below its threat point.

Table (10) reports the partition function values and summarizes the coalition structure's stand-alone stability.

Table (10) clearly shows that positive externalities do exist in this game:

$$V(EU, \{(FO, IS, NO), (EU), (RU)\}) = 0.48$$

$$> \begin{cases} V(EU, \{(FO, IS), (EU), (NO), (RU)\}) = -0.28 \\ V(EU, \{(FO, NO), (EU), (IS), (RU)\}) = -0.10, \end{cases}$$

Table 10: Coalition Structures, Partition Function Values, and Stand-Alone Stability.

Coalition Structure	$V(S_k, C)$	$V_i(S^i, C_i)$	Stand-Alone Stable
(EU,FO,IS,NO),(RU)	1.00	0.48, 0.68, 0.50, 0.53	No
(EU,FO,IS),(NO),(RU)	0.22	-0.28, 0.34, 0.06	Yes
(EU,FO,NO),(IS),(RU)	0.25	-0.10, 0.35, 0.00	No
(EU,IS,NO),(FO),(RU)	0.15	0.60, -0.10, -0.05	No
(FO,IS,NO),(EU),(RU)	0.22	-0.14, -0.03, 0.21	Yes
(EU,FO),(IS),(NO),(RU)†	-0.07	0, 0	No
(EU,IS),(FO),(NO),(RU)†	0.51	0, 0	Yes
(EU,NO),(FO),(IS),(RU)†	0.39	0, 0	Yes
(FO,IS),(EU),(NO),(RU)†	0.61	0, 0	Yes
(FO,NO),(EU),(IS),(RU)†	0.43	0, 0	Yes
(IS,NO),(EU),(FO),(RU)†	0.24	0, 0	Yes
(EU,FO),(NO,IS),(RU)	0.49, 0.58	0.60, -0.14, 0.00, 0.06	Yes
(EU,IS),(FO,NO),(RU)	0.98, 0.48	-0.10, -0.03, 0.34, -0.05	Yes
(EU,NO),(FO,IS),(RU)	0.88, 0.53	-0.28, 0.21, 0.35, -0.10	Yes
(EU),(FO),(IS),(NO),(RU)	0, 0, 0, 0	0, 0, 0, 0	Yes

†The Nash equilibrium is not unique.

$$V(FO, \{(EU, IS, NO), (FO), (RU)\}) = 0.68$$

$$> \left\{ \begin{array}{l} V(FO, \{(EU, IS), (FO), (NO), (RU)\}) = 0.34 \\ V(FO, \{(EU, NO), (FO), (IS), (RU)\}) = 0.35 \\ V(FO, \{(IS, NO), (EU), (FO), (RU)\}) = -0.14, \end{array} \right.$$

$$V(IS, \{(EU, FO, NO), (IS), (RU)\}) = 0.50$$

$$> \left\{ \begin{array}{l} V(IS, \{(EU, FO), (IS), (NO), (RU)\}) = 0.06 \\ V(IS, \{(FO, NO), (EU), (IS), (RU)\}) = -0.03 \\ V(IS, \{(EU, NO), (EU), (FO), (RU)\}) = -0.10, \end{array} \right.$$

and

$$V(NO,\{(EU,FO,IS),(NO),(RU)\}) = 0.53$$

$$> \begin{cases} V(NO,\{(EU,IS),(FO),(NO),(RU)\}) = -0.05 \\ V(NO,\{(FO,IS),(EU),(NO),(RU)\}) = 0.21 \\ V(NO,\{(EU,FO),(IS),(NO),(RU)\}) = 0.00. \end{cases}$$

In the presences of externalities, Pintassilgo (2003) established that *"A sufficient condition for a coalition structure not to be stand-alone stable is that the sum of the normalized values of the singleton coalitions, resulting from unilateral deviations from any of its coalitions, exceeds the value of that coalition"* (Lemma 2, page 185). In this respect the coastal state coalition cannot be stand-alone stable. This can be seen by calculating the sum of the values of the singleton coalitions, resulting from unilateral deviations from the coastal state coalition.

$$\sum_{i=1}^{n} V_i(S^i, C_i) = 0.53 + 0.50 + 0.68 + 0.48 = 2.20 > V(S_k, C) = 1.00$$

As the value of the unilateral deviations from the coastal state coalition exceeds unity, it can be concluded that there is no sharing rule that can make the coastal state coalition stand-alone stable. Therefore, the coastal state coalition cannot be a Nash equilibrium of the Exclusive Membership game.

In order to find the possible equilibrium coalition structures we need to find those that are not just stand-alone stable but also where the players find it unprofitable to join others in forming larger coalitions too.

Following Definition 5, the coalition structures {(EU,FO,IS),(NO),(RU)}, {(FO,IS,NO),(EU),(RU)}, {(EU,IS),(FO),(NO),(RU)}, {(EU,NO),(FO),(IS),(RU)}, {(FO,IS),(EU),(NO),(RU)}, {(FO,NO),(EU),(IS),(RU)}, {(IS,NO),(EU),(FO),(RU)}, {(EU,FO),(NO,IS),(RU)}, {(EU,IS),(FO,NO),(RU)}, {(EU,NO),(FO,IS),(RU)} and {(EU),(FO),(IS),(NO),(RU)} happen to be stand-alone stable. However, it is interesting to note that none of them is a Nash equilibrium of the Exclusive Membership game.

Regarding the {(EU,FO,IS),(NO),(RU)}, Norway has incentive to join the other coastal states if it receives at least 0.53. As the coalition (EU,FO,IS) only receives 0.22 when Norway plays as a nonmember, and the coalition consisting of EU, the Faroe Islands, Iceland, and Norway, with Russia as an outsider, receive 1.00, there is here a Pareto-sanctioned movement. Likewise for the {(FO,IS,NO),(EU),(RU)}, the EU has incentive join the coastal state coalition if it at least receives 0.48, while the others receive 0.22 when EU plays as a nonmember. The two-player coalitions {(EU,IS),(FO),(NO),(RU)}, {(EU,NO),(FO),(IS),(RU)}, {(FO,IS),(EU),(NO),(RU)}, and {(FO,NO),(EU),(IS),(RU)} are either better off as they are without merging with one of the singletons to form a three-player coalition, or such a merger would not result in benefits large enough to leave all players as least as well off. What is more attractive is for the singletons to merge and form a two-player coalition for themselves. However, for the {(EU,IS),(FO),(NO),(RU)}, {(EU,NO),(FO),(IS),(RU)}, and {(FO,IS),(EU),(NO),(RU)} this is not a Pareto-sanctioned movement, as the initial two-player coalitions are are worse off in a {2,2,1} coalition structure. For the {(IS,NO),(EU),(FO),(RU)}, on the other hand, Iceland and Norway are as least as well off merging with the Faroe Islands forming a three-player coalition. This is not a Pareto-sanctioned movement either since EU's payoff as a singleton was 1770 under the former coalition structure while only 1542 in the latter case. However, a movement from {(IS,NO),(EU),(FO),(RU)} to {(EU,FO),(NO,IS),(RU)} would be a Pareto-sanctioned improvement, as all players would be as well off in the latter case as in the former. With regard to the {(EU,FO),(NO,IS),(RU)}, {(EU,IS),(FO,NO),(RU)} and {(EU,NO),(FO,IS),(RU)}, the sum of the payoff of the two-player coalitions is less than the payoff to the coastal states when they all cooperate. Finally, there is the {(EU),(FO),(IS),(NO),(RU)}, which is stand-alone stable by definition, but not a Nash equilibrium in the game. Although not necessarily a Pareto-sanctioned movement, every

Table 11: Sensitivity Analysis.

	Stand-Alone Stability							
	Initial Year		Discount Rate		Cost parameters			
					X^{∞}		c_i	
Coalition Structure	2006	2000	4%	6%	-1%	+1%	-10%	+10%
(EU,FO,IS,NO),(RU)	No	No	No	No	No	No	No	No
(EU,FO,IS),(NO),(RU)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
(EU,FO,NO),(IS),(RU)	No	No	Yes	Yes	Yes	No	No	No
(EU,IS,NO),(FO),(RU)	No	No	Yes	Yes	No	Yes	No	Yes
(FO,IS,NO),(EU),(RU)	Yes	No	Yes	Yes	No	Yes	Yes	No
(EU,FO),(IS),(NO),(RU)	Yes†	No	Yes†	Yes†	No†	Yes†	Yes†	No
(EU,IS),(FO),(NO),(RU)	Yes†	Yes†	Yes†	Yes†	No	Yes†	Yes†	Yes†
(EU,NO),(FO),(IS),(RU)	Yes†	Yes†	Yes†	Yes†	No	Yes†	Yes†	Yes†
(FO,IS),(EU),(NO),(RU)	Yes†	Yes†	Yes†	Yes†	No	Yes†	Yes†	Yes†
(FO,NO),(EU),(IS),(RU)	Yes†	Yes†	Yes†	Yes†	No	No†	Yes†	No
(IS,NO),(EU),(FO),(RU)	Yes†	No	Yes†	Yes†	No	Yes†	Yes†	No
(EU,FO),(NO,IS),(RU)	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
(EU,IS),(FO,NO),(RU)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
(EU,NO),(FO,IS),(RU)	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
(EU),(FO),(IS),(NO),(RU)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

†The Nash equilibrium is not unique.

country will be at least as well off by unilaterally merging with another country to form a two-player coalition while the other players act as nonmembers.

Be aware that most of the results derived above, and in the following, will be contingent on our choice of equilibria selection criteria for the coalition structures with nonunique payoff vectors. However, what is certain is that a coalition of all coastal states is not a Nash equilibrium in the two-stage game.

5.2 Sensitivity analysis

In order to check the robustness of our results to changes in initial age group abundances, the discount rate and in the cost parameters we have performed an sensitivity analysis. Table (11) reports the results of this. For comparison, the results in the last column of Table (10) are repeated.

Choosing the age distribution of the stock in 2006 as initial age group abundance in the simulations is natural because 2006 is the first year of the blue whiting agreement, and investigating the stability of the coastal state coalition from this point of departure is therefore highly relevant. However, there have been difficulties reaching this agreement and the process leading up the agreement has taken several years, and so it would be of interest to see if the prospects looked different at the beginning of this process than at the end of it. Therefore, Table (11), third column, presents the stand-alone properties of simulations with 2000 as initial year, *ceteris paribus*. The coastal state coalition is not stand-alone stable, and fewer coalition structures had multiple best response equilibria. Although fewer of the coalition structures are stand-alone stable compared to 2006, one of them, the {(EU,NO),(FO),(IS),(RU)}, is a Nash equilibrium. None of the countries would be better off by any unilateral movement away from this coalition structure.

Next, we see that the main results are robust to small changes in the discount rate. However, at discount rates of 4 and 6%, every coalition structure except the coastal state coalition, is stand-alone stable. At 5% discount rate, on the other hand, the number of stand-alone stable coalition structures is lower, indicating an ambiguous effect of discounting in a complex problem such as this.

We continue testing the robustness of the results to changes in the cost parameters. Firstly, we change the effort level X^∞ by plus/minus one percentage point. An increase (a decrease) in X^∞ means that the stock is fished down to minimum more rapidly (slowly). Having done this the cost parameters are re-calibrated. This is equivalent to a reduction (an increase) in the cost parameters *ceteris paribus*, but in fact change in the cost parameters are much higher than the original change in X^∞. By increasing X^∞ we end up with five Nash equilibrium coalition structures, {(EU,IS),(FO,NO),(RU)}, {(EU,NO),(FO,IS),(RU)}, {(EU,FO),(NO,IS),(RU)}, {(EU,IS),(FO,NO),(RU)} and {(EU,NO),(FO,IS),(RU)} while lowering X^∞ result in fewer stand-alone stable coalition structures, fewer nonunique payoff vectors and one Nash equilibrium coalition structure: the {(EU,IS),(FO,NO),(RU)}.

Secondly, since a small change in X^∞ gives large and disproportionate changes in the cost parameters, we change, *ceteris paribus*, the cost parameters, c_i, directly. Again we see that increased costs increases the number of coalition structures with a unique Nash equilibrium, however, to a lesser extent than lowering X^{∞} would. When reducing the cost of unit effort by 10%, the (IS,NO),(EU),(FO),(RU) emerges as a Nash equilibrium coalition structure.

What has become evident by this exercise is that the coastal state coalition cannot be a Nash equilibrium of the blue whiting game under the Exclusive Membership rules. However, under some circumstances a few other coalition structures emerged as possible candidates for being a Nash equilibrium, but this only holds if our equilibrium selection criteria is the correct one. Moreover, the higher the cost of fishing, fewer of the coalition structures are stand-alone stable and none is a Nash equilibrium.

5.3 Coalition Unanimity

In the light of the results reached so far, a successful coastal state agreement on the management of the blue whiting fishery seems an unlikely outcome. In spite of this an agreement was reached in 2005, implemented in 2006, and is still in function.

One possible explanation for this is that the game is governed by the Coalition Unanimity game rule rather than the Exclusive Membership rules. That is, there are only two feasible coalition structures, the coastal states forming a coalition with Russia as a singleton or no cooperation at all, as opposed to a continuum of partial cooperative coalition structures between the two alternatives.

We have already shown, cf. Equation (7), that the coastal state cooperative agreement has a positive present value, $V^{*}(C_{CS}, C_{CS})$, under the Coalition Unanimity game rule. Thus, imposing this restriction on the game, the {(EU,FO,IS,NO),(RU)} becomes a stand-alone stable coalition structure and the coastal state coalition a Nash equilibrium in the blue whiting game.

However, it is not easy to decide what type of rules are best suited for describing the blue whiting fishery game. Moreover, the conditions of the game may be changing over time due to changes in the natural environment such as climate change, changes in the migration pattern or in the abundance of fish, or a successful management might attract newcomers who start fishing blue whiting on the high seas. Such factors might change how the game should be played completely.

Then there is the question of what kind of game is it at present; a Coalition Unanimity game or a Exclusive Membership game? The coastal states' initial claims of shares in the fishery is an argument in favour of the Exclusive Membership game in that they all seemed to demand at least their free rider payoffs to be willing to cooperate. This is exactly what made the coastal state coalition unstable in the first place. Argument in favour of the Coalition Unanimity game is that there is little evidence of coastal states forming coalitions consisting of only two or three members, although there was an extensive exchange of quotas which allowed foreign vessels to fish blue whiting inside national EEZs, including Russia. Remember that in the Exclusive Membership game a player was willing to form a coalition with any other player that it included in its own announcement. The probability that the remaining members of the coastal state coalition would continue as a smaller coalition while an individual member decides to leave the coalition and form a singleton coalition on its own is very low. In that event, the desire to punish the free rider becomes strong and the incentive for conservation weaker.

6 Concluding remarks

This paper applies the coalition approach to management of high seas fisheries in the presence of externalities to the North East Atlantic blue whiting fishery. The international management of this fishery is conducted through the coastal states and not a regional fisheries management organization. The coastal states agree on, and divide among themselves, a total allowable catch for the stock. A fraction of this TAC is to be fished on high seas and is supposed to be shared by both the coastal states and distant water fishing nations. The division of the high seas shares is left to the local RFMO, the North

East Atlantic Fisheries Commission.

In order to account for these features we focused on partial rather than full cooperation, in particular coalitions among the coastal states. We found that, allowing for multiple coalition structures, the coastal state coalition is not a Nash equilibrium coalition structure. This was the outcome of the Exclusive Membership game.

This result is in line with previous studies using two-stage partition games. Pintassilgo (2003), using an age-structured, multi-gear bioeconomic model, shows that for the Northern Atlantic bluefin tuna fishery, there is no sharing rule that makes the grand coalition stable and no Nash equilibrium coalition structure exists. However, if we restrict the number of feasible coalition structures among the coastal states, such that the game is governed by the Unanimity Coalition game rule, the coastal state coalition becomes a stable Nash equilibrium.

The agreement among the coastal states established in 2005 does not prove that the blue whiting fishery is best described as a Unanimity Coalition game. The process leading up to the agreement must be said to have been both long and hard. The uncertainty about the rules of the game and its dependency on a constantly changing environment, both in a literal, and in a political and institutional sense, makes the long term prospects of the agreement uncertain too. Unless the individual coastal states receive a sufficiently high share of the gains of cooperation, the incentives to act noncooperatively will remain strong.

The prospects of cooperation among the coastal states are low if countries can free-ride on the cooperative agreement. This survey has shown that it is not only distant water fishing nations and interlopers that threaten the stability of fisheries agreements, the self interests of the coastal states are a major obstacle for cooperative management of straddling fish stocks. This is the opposite of what was used as an argument for the establishment of exclusive economic zones in the first place, *i.e.*, that the tragedy of the commons in international fisheries would be virtually eliminated as 90% of the world's fisheries resources would become subject to national jurisdiction. Furthermore, the shortcomings of the United Nations Convention on the Law of the Seas soon became evident; as a significant part of the fisheries moved to international waters in response to the extension of national jurisdiction. The United Nations Fish Stock Agreement was supposed to help solve this problem by, among other measures, prohibiting states that do not abide by the regime of the regional fishery organization from fishing the resource. But it is almost impossible to prohibit any state from fishing on the high seas let alone within waters under its own jurisdiction. Perhaps the next step in trying to protect fish stocks from over-exploitation would be to reduce the sovereignty of the coastal state and transferring it to the RFMOs instead?

The stability of existing coastal state agreements will be put to the test by fish stocks changing their distribution in response to climate change. Fish stocks will migrate into new waters and become available for harvest in EEZs of nonmember nations to the management agreement of the stock in question, disrupting the balance of the agreed sharing rule. This might lead to increased fishing pressure as the new coastal states try to establish so called historical fishing rights. Recently, two other straddling fish stocks distributed in the same waters as the blue whiting have experienced this.

As examples of the contemporary problem with straddling, shared stocks in this area, we have the agreement between the coastal states on the Norwegian Spring-spawning herring stock. This agreement broke down, and was suspended in 2003 and 2004, when the stock did not resume its expected migration pattern. Norway, especially, was not satisfied with its share in the fishery when it turned out that the stock actually spent more time in Norwegian waters then what was expected when the agreement was set up. Luckily, the dispute did not last long and the stock was in good condition to withstand an increased fishing pressure for a short while.

Secondly, the Northeast Atlantic mackerel has moved its distribution northwards and is currently available during summer and autumn in Icelandic waters. Iceland, which is not a member of the management agreement of this stock, fished significant amounts of mackerel in 2007 and 2008. This comes in addition to the landings of the member countries, leading to a total harvest in excess of the ICES's recommendations for this stock. Moreover, the Northeast Atlantic mackerel stock is probably in a poorer condition than the Norwegian Spring-spawning herring was in when its management agreement was suspended, and when it was renewed, no new members were included.

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