Essays on the Economics of Shared Fishery Resources

by

Nils-Arne Ekerhovd

Dissertation submitted in partial fulfillment of the requirements for the *Philosophiae Doctor* (PhD) degree at the Norwegian School of Economics and Business Administration, Department of Economics.

Bergen, October 2008

Acknowledgements

First, I would like to thank my supervisor, Rögnvaldur Hannesson. I am highly indebted to him for his encouragement, support and patience. I would also like to thank the other two members of my advisory committee, Trond Bjørndal and Veijo Kaitala. The research has been carried out, with financial assistance from the Norwegian Research Council, at the Department of Economics at the Norwegian School of Economics and Business Administration (NHH), Department of Economics at the University of Calgary (UofC) and the Institute for Research in Economics and Business Administration (SNF). I wish to acknowledge the hospitality I received at UofC. I especially want to thank Dan Gordon for hosting me and helping me in my research. I am further thankful to SNF for hiring me and giving me the opportunity to finish my dissertation. Thanks to the faculty, staff and fellow students at the Department of Economics at NHH for making it an enjoyable place to work. Finally, thanks goes to friends and relatives for the support and encouragement they have given me over the years. Special thanks to my brother and sister, Helge and Gjertrud, and our father, Knut.

Bergen, 8th October 2008

Nils-Arne Ekerhovd

Contents

List of Figures

List of Tables

Introduction

The classic economic theory of fisheries management was concerned with two contrasting systems of property rights: (i) sole ownership and (ii) open access. With regard to economic rents, these two systems yield unique outcomes. First, sole ownership results in rent maximization, where the marginal productivity of the factors of production equals the marginal cost, such that the condition for economic efficiency is satisfied. Second, open access results in what one of the pioneers of modern fisheries, H. Scott Gordon, characterized as "bionomic equilibrium" (Gordon, 1954). Here the marginal productivity is less than marginal cost, such that there will be an overuse of factors of production. Driving the fish stock below its economically optimal level implies a disinvestment in the fisheries' natural capital (overexploitation) (Clark, 1990). Hence bionomic equilibrium is to be seen as a benchmark of poor resource management.

Rapid advances in fishing technology, for example the introduction of the power block, along with acoustic fish detection devices, revolutionized the purse seine fishery, reduced harvesting costs and thereby increased the vulnerability of pelagic ocean fishery resources. While the overexploitation of the great ocean fishery resources was not a concern until the first half of the twentieth century because these resources were seen as being inexhaustible (Munro, 2008); with the collapse of many commercial fisheries, *e.g.* the Northeast Atlantic herring fisheries in the 1960s and 1970s, it became evident that regulations of some kind were needed to avoid rent dissipation in commercial fisheries.

Following the end of World War II, several coastal states attempted, unilaterally, to extend their jurisdiction over seabed resources beyond their territorial seas. In order to prevent a chaotic extension of coastal state marine jurisdiction, the United Nations convened a series of Conferences on the Law of the Sea. The First and Second Conferences failed to reach agreement on jurisdiction over the living resources of the sea (Hannesson, 2004), despite spending much time on fisheries issues. The Third Conference (1973-82) revolutionised the jurisdictional regime for marine capture fisheries, and led, through the establishment of the exclusive economic zone (EEZ), to a massive erosion of the freedom of the seas doctrine[1], as it relates to fisheries. With only 10 % of capture fishery harvests being accounted for by fishery resources in the remaining high seas, the freedom of the seas seemed, as far as fisheries were concerned, to be all but irrelevant in 1982 (Munro, 2008).

One can distinguish between three types of internationally shared fish stocks. First, there are the transboundary fishery resources; fish stocks that migrate between the EEZs of two or more coastal states. Second, we have the so-called ‘straddling’ fish stocks, *i.e.*, those stocks that migrate between the EEZ of one or more coastal states and the high seas (Bjørndal and Munro, 2003). Third, there are the highly migratory fish stocks, *i.e*, fish stocks that are confined to the remaining high sea, and which in effect refers to tuna (Sumaila, 1999).

Economists cannot analyse the economics of the management of internationally shared fishery resources, with the hope of providing useful insights to policymakers, without recognising that there will be strategic interaction between states sharing a fishery resource. The harvesting activities of one state will, except under unusual circumstances, have an impact upon the harvesting opportunities of other states, and vice versa; hence the strategic interaction. For this reason, economic models of shared fish stocks blend the bioeconomic models, used to analyse the economics of the management of fishery resources confined to the EEZ of a single state, with game theory.

---

[1] Under this doctrine, as propounded by the seventeenth-century Dutch jurist, Hugo Grotius, in his volume *Mare Liberum* (“The Free Sea”), the oceans are classified either as the territorial sea of coastal states or (the remainder) as the high seas. The territorial sea is a narrow strip of water, by tradition no wider than three nautical miles, but extends now to 12 nautical miles (Munro, 2008).

With this in mind, when approaching the issue of the management of transboundary fish stocks, one has to address the two following questions:

i) What are the consequences of coastal states sharing such a resource managing the resource noncooperatively?
ii) What conditions must be met if a cooperative fisheries management arrangement is to be stable in the long run?

The first question is addressed by drawing upon the theory of noncooperative games, with the model of Nash (1951) being the most popular among economists. The question was first examined in 1980 in two articles appearing almost simultaneously, one by Clark, and another by Levhari and Mirman. Both come to essentially the same conclusion, namely that one can anticipate a prisoner's dilemma type of outcome, in which the coastal states will be driven to adopt policies that will lead to overexploitation of the resource. Clark goes as far as to argue that if the coastal states are symmetric, the outcome will be comparable to the bionomic equilibrium in open access fisheries confined to a single EEZ (Clark, 1980).

Chapter 1 of my thesis, "*The Effects of Different Strategic Variables in Noncooperative Fisheries Games*"[2], addresses, by extending the harvest game model of Clark (1980), the principal question of what the choice of strategic variable has to say for this result. In the paper I use stock size, harvest quantity, and fishing effort as strategic variables. Effort is the product of effort flow and the duration of the flow, which is referred to as fishing capacity and season length, respectively. The model is a two-agent noncooperative fishery game, where the agents (the coastal states) harvest a common fish stock. The planning horizon is infinite. The net present values of fishing and the escapement stock level from using stock size, harvest quantity, fishing capacity and season length one at a time as strategic variables show how the choice of variables affects the results. The

---

[2] A version of this chapter has been accepted for publication in *Natural Resource Modeling*.

results show that using fishing capacity as the strategic variable produces the lowest net present value and the lowest escapement level, whereas the fixed harvest quantity strategy has the highest economic value and the highest escapement level. Further, using stock size as the strategic variable produces a net present value and escapement level slightly higher than when using fishing capacity as the strategic variable, whereas using season length as the strategic variable produces a net present value and escapement level slightly lower than with the fixed harvest quantity as the strategic variable. In all these cases, the harvest elasticity with respect to stock size equals one. However, as this elasticity approaches zero, the results change when it comes to the escapement levels. Now, with fishing capacity, stock size, and harvest quantity as strategic variables, the escapement levels approach zero, whereas the season length strategy maintains a strictly positive and viable escapement level even when the so-called stock effect is low and the risk of extinction is high.

The basic nature of the prisoner's dilemma outcome, in a fisheries context, can be illustrated as follows. Consider a fishery resource shared by two coastal states, A and B, and suppose further that there is no resource management cooperation between the two. A and B manage their respective fleet segments harvesting the resource on their own. If A were to restrict harvest in order to invest in the resource, the benefits from this action would not be enjoyed by A alone, but would be shared with B. What assurance would A have that B would also undertake conservation? Since there is no cooperation, the answer is none. It is possible that B would be content to be a free rider, taking advantage of A's resource investment efforts. In these circumstances, it is likely that A will conclude that the return on its resource investment would be less than the cost, and that the best course of action would be to do nothing. B could be expected to come to the same conclusion. Worse, A has to allow for the possibility that B might deliberately deplete the resource. If A believes this to be true, then it could find that its best interest is to strike first. Once again, B could follow the same line of reasoning (Clark, 1990). Thus one can conclude that a failure by neighbouring coastal states to cooperate could have severe consequences.

In analysing cooperative resource management arrangements, economists naturally draw upon the theory of cooperative games, with the model of Nash (1953). The number of coastal states involved in a typical transboundary fishery arrangement is small, so that considerable progress can be made with simple two-player models (Munro, 1979).

The simple two-player cooperative game models bring to light two fundamental conditions that must be met if the cooperative resource management arrangement is to be stable. The first condition is straightforward, and easily described. The solution to the cooperative game; the cooperative management agreement, must be collectively rational, in the sense that there does not exist another agreement that could make one player better off without harming the other players.

The second condition is that the solution must be individually rational, in the sense that each and every player has to be assured of receiving a payoff from the cooperative arrangement at least as great as it would receive under noncooperation. This assurance has to last throughout the life of the arrangement. In game-theoretic terms, these minimum payoffs are referred to as threat point payoffs, and are normally assumed to be those arising from the solution of a noncooperative game.

The anticipation that fishery resources in the remaining high seas beyond the EEZs would be of minor importance proved to be dramatically wrong. Following the Third United Nations Conference on the Law of the Sea, there was extensive exploitation of the high seas segments of straddling stocks, which undermined coastal state attempts to manage those stocks found within the EEZs.

An example is provided by blue whiting, one of the most abundant fish species in the Northeast Atlantic. The blue whiting stock straddles the EEZs of the EU, the Faroe Islands, Iceland and Norway, and the high sea areas of the Northeast Atlantic. During the period 1970-1997, the blue whiting fishery was dominated by the Russian Federation (former Soviet Union) and Norway, which developed it. Since the late 1990s there has been an increased interest in the blue whiting fishery, and the total landings increased from about 650 thousand tons in 1997 to 2.4 million tons in 2004. Iceland, which previously had for a large part ignored the blue whiting fishery, began to substantially increase its blue whiting landings from 1998 on. Since 1999, there have been several attempts among the coastal states of the European Union (EU), Norway, Iceland, and Denmark (on behalf of the Faroe Islands and Greenland), and Russia to reach an agreement and set a common maximum total allowable catch (TAC). Anticipating that an agreement would be reached some time in the future, the nations competed in catching blue whiting in an attempt to establish rights in the fishery and the best possible bargaining position for a future TAC. Meanwhile, the negotiations failed because each nation demanded a higher share of the quota than the others were willing to accept (Standal, 2006).

The growing concern over the state of the world's straddling fish stocks led the United Nations to convene an international conference to address the issue, the United Nations Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks (1993-1995), which in 1995, adopted what is commonly referred to as the UN Fish Stocks Agreement. The agreement, which achieved the status of international treaty law in late 2001, is not meant to replace any part of the 1982 Convention, but is rather designed to supplement and support the Convention (Bjørndal and Munro, 2003).

Under the terms of the UN Fish Stocks Agreement, straddling stocks are to be managed on a region-by-region basis through regional fisheries management organizations (RFMO). The precursors of today's RMFOs appeared first in the form of international conventions designed to put restrictions on fishing activities in certain segments of the high seas[3]. The RFMOs are to have as members both coastal states and distant water fishing nations (DWFN)[4].

The question then becomes, to what extent do the economic game theory models developed for transboundary fish stocks have to be modified when dealing with straddling

---

[3] An example is the 1953 "Permanent Commission", from 1964 known as the North East Atlantic Fisheries Commission (NEAFC), which attempted to impose some management rules over the high seas fisheries in the Northeast Atlantic (Engesæter, 2003).

[4] Examples are provided by the Northwest Atlantic Fisheries Organization, the North East Atlantic Fisheries Commission, and the Western Central Pacific Fisheries Convention (Munro, 2008).

fish stocks? One part of this question has already been answered. The model of noncooperative management of transboundary fish stocks can be applied with some modification to straddling fish stocks (Sumaila, 1999).

However, when we turn to the cooperative management of the resources, the answer is quite different. The economic game theory model of cooperative management of transboundary stocks requires substantial modification when the issue of cooperative management of straddling fish stocks is confronted. First, one can anticipate that the number of players in the typical straddling stock game will be large. In the analysis of transboundary fish stock management, considerable progress can be made using two-player models. Two-player models are simply inadequate for straddling stocks. Economists are compelled to employ models in which the number of players exceeds two, often by a wide margin. This, in turn, means that they have to allow for the possibility that players will form subcoalitions. The coalition of all players together in a fisheries game is referred to as the grand coalition.

With subcoalitions possible, it is no longer sufficient to be concerned about the individual rationality condition being satisfied. For the solution of the cooperative game to be stable through time, the solution must also be such that no subcoalition believes that it would be better off on its own, playing competitively against the remaining members of the grand coalition.

Second, in contrast to transboundary stock management, the number and nature of the players cannot be expected to be constant through time. Some members of the RFMO are DWFN. An orginal member of an RFMO may withdraw. More importantly, a DWFN, until now not a member of the RFMO, may apply for membership. The UN Fish Stocks Agreement makes it clear that the existing members of an RFMO cannot bar prospective new member outright. This gives rise to the so-called new member problem (Kaitala and Munro, 1993).

The third difference falls under the heading of free riding, which can be defined as enjoyment of the fruits of cooperation by nonparticipants in the cooperative management arrangement.

Applied game theorists, using what is known as a coalition bargaining approach, have addressed the free-riding problem in straddling stock management (Pintassilgo, 2003; Pintassilgo and Lindroos, 2008). The fundamental concept of stand-alone stability is introduced. The grand coalition, *i.e.*, an RFMO, is stand-alone stable if "no player is interested in leaving the cooperative agreement to adopt free-rider behavior" (Pintassilgo, 2003: 183).

Pintassilgo (2003) applies this coalition bargaining analysis to the case of the bluefin tuna fishery of the Eastern North Atlantic and Mediterranean, which is currently under the management of an RFMO in the form of the International Commission for the Conservation of Atlantic Tuna. He argues convincingly that, if there are no effective curbs on unregulated fishing, the grand coalition of the players in the Eastern North Atlantic and Mediterranean bluefin tuna fishery game is not stand-alone stable. In other words, the RFMO can be expected to collapse. If unregulated fishing would be effectively curbed, the prospects for the RFMO are much brighter.

Three of the four chapters of my thesis elaborate on the management of internationally shared fish stocks, in particular, the blue whiting (*Micromesistius Poutassou* Risso) stock. This stock migrates between the EEZs of the coastal states, consisting of the EU, the Faroe Islands, Iceland and Norway, and the high sea areas in the Northeast Atlantic, where it is harvested by fishing vessels from the Russian Federation, in addition to the coastal states' fishing fleets. However, due to the lack of international agreement for many years on how to divide a TAC among the nations, there was no agreed catch limit. This led to catches (and TACs) well above the ICES advice, and the blue whiting fishery is thus not considered sustainable.

On 16 December 2005, after six years of negotiations, the coastal states (the EU, the Faroe Islands, Iceland and Norway) reached consensus on the management and allocation of the blue whiting stock through an "Agreed record of conclusions of fisheries consultations", limiting the catches of blue whiting for the coastal states to no more than

2 million tonnes for 2006. Pursuant to the agreement, until the fishing mortality has reached a set target level, the Parties agree to reduce their TAC of blue whiting by at least 100,000 tonnes annually. When the target fishing mortality rate has been reached, the Parties shall limit their allowable catches to levels consistent with a precautionary fishing mortality rate as defined by ICES. The agreed TACs for 2007 and 2008 were 1.7 million tonnes and 1.25 million tonnes, respectively. These catch levels are expected to lead to fishing mortality rates well above the precautionary level.

Chapter 2, "*The Blue Whiting Coalition Game*", is an application of Pintassilgo's (2003) framework for analysis of coalition, in particular the partition function approach, to the Northeast Atlantic blue whiting fishery. The blue whiting stock migrates between the EEZs of different countries and also straddles into the high seas where it is accessible for all countries. Only recently was an agreement reached about the division of a global catch between the countries fishing the stock. The work done on this issue looks at all possible coalitions of countries fishing the stock. The main finding is that coalitions will typically be unstable, which means that agreements on sharing the stock are unlikely to be attained and, if attained, may be expected to fall apart. The possibility that a subset of coastal states will be able to form a partial coalition is most threatening to a stable coalition, while a coalition of coastal states is most likely to be stable if one member's defection would cause it to fall apart entirely.

The blue whiting stock is expected to change its distribution, spawning areas and migration pattern due to climate change. Recently, in years with a relatively warm ocean climate, juvenile blue whiting has appeared in great abundance in the southwesterly parts of the Barents Sea. Currently, the blue whiting stock's main spawning areas is west of the British Isles, but some spawning takes place along the coast of Norway as well as in the Norwegian fjords (Anon., 2008). An interesting question regarding the distribution of the stock is how cooperative agreements on the blue whiting are likely to be affected by climate change.

Chapter 3, "*Climate Change and the Blue Whiting Agreement*", investigates this. Two climate scenarios are considered: 1) warming that causes the stock to move into the Barents Sea and makes Russia a coastal state; 2) cooling that leads to a more westerly distribution of the stock, in which case Russia is not a coastal state. Scenario 1) increases the likelihood of a stable coalition.

Until recently, the blue whiting fishery was unregulated. Unlike the other papers in my thesis, the focus of chapter 4, "*Increased Fishing Pressure on Unregulated Species: The Norwegian Blue Whiting Fishery*", is not on the game-theoretic aspects of the fishery. The purse seine fleet analysed also harvests other species, some of which are regulated while others are not. In an empirical, application the study analyses how landings of blue whiting depend on their own price, prices of other species, and the price of fuel as well as quotas and landings of other fish stocks. The results presented are, of course, fishery-specific. Nevertheless, a fleet harvesting a straddling stock may also exploit other stocks, outside or inside an EEZ. The contribution of this paper is to show that knowledge about these interactions is necessary for efficient management.

National jurisdiction over the fishery resources within the EEZ can be seen as an opportunity to overcome the problem of open access within the EEZs, but not on the high seas. Traditionally, it has been everybody's right to exploit the resources there. This right is now possibly under threat, cf. the UN Fish Stocks Agreement; however, it is still very much a juridical twilight zone. On the high seas, to some degree at least, open access is still the rule rather than the exception. Moreover, agreements between nations have to be based on voluntary cooperation, because there is no mechanism forcing nations to agree to something that would not be in their own interests. Therefore, this work is to a large degree about the possibility of overcoming the problem of open access through voluntary agreements.

Summing up, the questions analysed in the thesis covers several topics relevant to the fisheries economics literature. First, exploitation of internationally shared fish stocks is considered under different assumptions about the regulatory regime, coalition formation, climatic conditions *etc.* In this part of the thesis (chapters 1-3), bioeconomic modelling and game theory are fundamental tools. Second, the production structure and capacity utilisation in a segment of a fishing fleet is analysed by means of duality theory and econometric methods (chapter 4). The span in topics and methods are perhaps large, but the topics have at least one important common feature; they are all related to the management of internationally shared fish stocks and the consequences of strategic behaviour. The aim of the thesis is thus to contribute to the understanding of the economic management of shared fishery resources.

References

ANON. (2008): "Klimaendringer i Barentshavet (Climate Change in the Barents Sea) - Konsekvenser av økte CO_2-nivåer i atmosfæren og havet," ed. by H. Loeng. Rapportserie Nr. 126. Norsk Polarinstitutt (Norwegian Polar Institute), Tromsø, Norway.

BJØRNDAL, T., AND G. R. MUNRO (2003): "The Management of High Seas Fisheries Resources and the Implementation of the UN Fish Stocks Agreement of 1995," in *The International Yearbook of Environmental and Resource Economics 2003-2004*, ed. by H. Folmer, and T. Tietenberg, New Horizons in Environmental Economics, chap. 1, pp. 1–35. Edward Elgar, Cheltenham, UK.

CLARK, C. W. (1980): "Restricted Access to Common-Property Fishery Resources: A Game-Theoretic Analysis," in *Dynamic Optimization and Mathematical Economics*, ed. by P.-T. Liu, chap. 7, pp. 117–132. Plenum Press, New York.

——— (1990): *Mathematical Bioeconomics: The Optimal Management of Renewable Resources*. John Wiley & Sons, Inc., New York Chichester Brisbane Toronto Singapore, 2 edn.

ENGESÆTER, S. (2003): "The importance of ICES in the establishment of NEAFC," http://www.neafc.org/document/icessymp.htm.

Gordon, H. S. (1954): “The Economic Theory of a Common Property Resource: The Fishery,” *Journal of Political Economy*, 62(2), 124–142.

Hannesson, R. (2004): *The Privatization of the Oceans*. The MIT Press, Cambridge, Massachusetts; London, England.

Kaitala, V., and G. R. Munro (1993): “The management of high sea fisheries,” *Marine Resource Economics*, 8, 313–329.

Levhari, D., and L. J. Mirman (1980): “The Great Fish War: An example using a Dynamic Cournot-Nash Solution,” *Bell Journal of Economics*, 11, 322–344.

Munro, G. R. (1979): “The Optimal Management of Transboundary Renewable Resources,” *Canadian Journal of Economics*, 3, 271–296.

——— (2008): “Game theory and the development of resource management policy: The case of international fisheries,” in *Game Theory and Policymaking in Natural Resources and the Environment*, ed. by A. Dinar, J. Albiac, and J. Sánchez-Soriano, Routledge Explorations in Environmental Economics, chap. 2, pp. 12–41. Routledge, London, UK; New York, USA.

Nash, J. F. (1951): “Non-Cooperative Games,” *Annals of Mathematics*, 54(2), 286–294.

——— (1953): “Two-person cooperative games,” *Econometrica*, 21, 128–140.

Pintassilgo, P. (2003): “A Coalition Approach to the Management of High Seas Fisheries in the Presence of Externalities,” *Natural Resource Modeling*, 16(2), 175–197.

Pintassilgo, P., and M. Lindroos (2008): “Application of partition function games to the management of straddling fish stocks,” in *Game Theory and Policymaking in Natural Resources and the Environment*, ed. by A. Dinar, J. Albiac, and J. Sánchez-Soriano, Routledge Explorations in Environmental Economics, chap. 4, pp. 65–84. Routledge, London; New York.

Standal, D. (2006): "The rise and decline of blue whiting fisheries - capacity expansion and future regulations," *Marine Policy*, 30, 315–327.

Sumaila, U. R. (1999): "A review of game-theoretic models of fishing," *Marine Policy*, 23(1), 1–10.

Chapter 1

The Effects of Different Strategic Variables in Noncooperative Fisheries Games

Abstract

In this paper we use stock size, harvest quantity, and fishing effort as strategic variables. We model a two-agent noncooperative fishery game, where the agents (nations) harvest a common fish stock. The planning horizon is infinite. The model is solved successively using one instrument at a time as the strategic variable in the game. The net present values of fishing and the escapement stock level from the three different models are compared to show how the choice of variables affects the results. The choice of strategic variable is not a trivial one, as the results are shown to be sensitive to the discounting, the stock's rate of growth, and the assumptions about the distribution of the fish in response to harvesting.

Keywords: Noncooperative resource games, open loop, strategic variables, regulation.

JEL Classification: Q20, H73, C72, Q22.

1.1 Introduction

In this paper, we will look at the implications of choosing different strategic variables, harvest quantity, stock size, and fishing effort, in noncooperative fisheries games. We will model a two-agent game, where the agents (nations) harvest a common fish stock. The planning horizon is infinite. The model will be solved successively using one instrument at a time as the strategic variable in the game. The net present values of fishing and the escapement[1] stock level from the three different models will be compared to show how the choice of variables affects the results.

The choice of strategic variables, be it fishing effort, harvest rate, or stock level, has rarely been discussed in the literature on fisheries and games. The choice of variables seems to be rather *ad hoc*. We came across only two papers that address the question of the choice of strategic variable and attempt to analyze what this choice might imply.

Vincent (1981) pointed out that different control variables can lead to different game solutions. He used a prey–predator model based on May *et al.* (1979) to analyze the vulnerability of a species to extinction by comparing the equilibrium solutions under an effort harvesting and a rate harvesting program. The analysis demonstrated that, in many cases, solutions from a constant harvest quantity strategy will not secure the species against possible extinction, and an adjustment of the harvest levels may be necessary.

The second paper addressing the choice of strategic variables is by Hämäläinen and Kaitala (1982), who analyzed a fishery divided between two countries. The model is an extension of the harvest game model of Clark (1980) (Kaitala, 1986). Each country manages the fishery as a sole owner within its respective exclusive economic zones. The authors asked how the sole-owner fleets should choose their policy variables (strategic variables) in the negotiations. The two countries have three options in their choice of policy variables: stock size, harvest rate, and fishing effort. Of the possible steady state Nash equilibria, the one where both countries have the harvest rate as their policy

---

[1] Escapement: the stock left behind after fishing.

variable produces the largest joint revenue flows and the largest stock levels. As perfect cooperation cannot be guaranteed, the Nash solution of the game is that both countries choose the stock level strategy, which results in an equilibrium with the lowest revenue flow of all the nine possible equilibria and the lowest stock levels.

As with Hämäläinen and Kaitala (1982), this paper analyzes a deterministic model where prices, costs, harvest, and growth functions are known and the same for all periods. However, while Hämäläinen and Kaitala considered a fishery divided into two interdependent subfisheries, each exploited by a sole owner, we examine a shared fish stock exploited by two nations in the same waters. Furthermore, Hämäläinen and Kaitala ignored the effects of transience of the strategic variables during the approach path, assuming that the stock is in a steady state initially. In this work, however, we assume that the stock is in a pristine state initially. When the fishing commences, the stock size approaches a new steady state. Reaching this new steady state might take several periods, depending on the strategic variable chosen.[2] For instance, with stock size as the strategic variable, the optimal steady state is independent of the initial stock size.[3] When either harvest quantity or fishing effort is chosen as the strategic variable, the optimal steady state does depend on the initial stock size.[4] Finally, another feature separating this paper from Hämäläinen and Kaitala's (1982) work is that while these authors assumed that the fish maintain a uniform distribution when harvested, we allow the harvest elasticity with respect to stock size to vary between zero and one. As the harvest elasticity with respect to stock size approaches zero, we obtain results similar to those found by Vincent (1981).

---

[2] When one assumes an initial steady state, it is clear that the choice of strategic variable is trivial, as is the case when the strategic variables are allowed to vary over time. However, if the stock is not in the steady state initially, and the strategic variables are held fixed over all periods, the steady state will depend on the choice of strategic variable.

[3] This means that as long as the initial stock size is larger than the steady state stock size, and stock size is the strategic variable, only one period of harvesting is needed to bring the stock size down to its optimal level. However, if the initial stock size for some reason is less than the steady state size, *i.e.*, if it is assumed that the stock is not in a pristine state initially, then a moratorium is needed in order to bring the stock size up to its optimal level. This might take more than one period, depending on the initial level and the growth of the stock.

[4] Fixing the harvest quantity or the fishing effort for all future periods may not be optimal in the long run, but it takes time to change at least some strategic variables, and it is appropriate in order to illustrate the difference between the variables.

How the players' strategy spaces are formulated is also an issue that should be addressed when modelling dynamic games. Two approaches have been adopted: the open loop solution, which assumes that commitment to a strategy extends over the entire future horizon; and the feedback solution, where the assumption is that no commitment at all is possible (Fudenberg and Tirole, 1991). This choice can be crucial, and care should be taken to choose a strategy space that is appropriate for the situation in question (Reinganum and Stokey, 1985).

With stock size as the strategic variable, both the harvest rate and fishing effort will change from the initial period until a steady state is achieved in both the stock size and the harvest rate. Harvest rate or fishing effort are not as flexible as stock size as strategic variables, although choosing either of them means that the other changes as the size of the stock is changed by the fishery. Because equilibria in both the harvest rate and the stock size are achieved so quickly when the escapement level is the strategic variable, we can assume that the formulation of the strategy space is of minor importance, *i.e.*, it is not particularly significant whether the solution is open loop or feedback. When using harvest rate or fishing effort as the strategic variable, however, it is harder to make the same justification.[5]

Amir and Nannerup (2006), however, considered the well-known Levhari and Mirman (1980) discrete-time model where the resource extraction is equal to consumption. This is equivalent to having the harvest rate as the strategic variable. Comparing the open loop and the feedback equilibria, Amir and Nannerup found that the open loop equilibrium coincides with the symmetric Pareto-optimal solution.[6] The feedback equilibrium leads

---

[5] Eswaran and Lewis (1985) compared the open loop and feedback Nash equilibria that are obtained in oligopolistic resource markets when the resource is exhaustible and privately owned, and demonstrated that there exist cases in which the open loop and feedback equilibria are identical. This is true when the demand function facing the industry is isoelastic and extraction costs are zero, or when a symmetric oligopoly faces linear demand and quadratic extraction costs. Moreover, in circumstances where the two equilibria do not coincide, simulation results revealed that the quantitative differences between the two equilibria are small.

[6] Finding the symmetric Pareto-optimal solution, Amir and Nannerup (2006) considered the sum of two agents' utilities, each of which were given equal weights. This is equivalent to the single agent problem and is solved in a feedback framework. Moreover, they stated that the open loop equilibrium coincides with a symmetric Pareto-optimal solution if, and only if, the externality under consideration

to overconsumption and a lower total discounted utility level for each agent relative to the symmetric Pareto-optimal solution. Moreover, Amir and Nannerup pointed out that if all players are using open loop strategies, a given player cannot unilaterally improve on his or her payoff by using more complex strategies.

We see that when the harvest rate, or fishing effort, is the strategic variable, the open loop equilibrium is Pareto-efficient, whereas with the escapement level as the strategic variable, the open loop and feedback equilibria coincide. When the solution concept is a closed loop (feedback), rather than an open loop, this means that harvest rate or fishing effort will not be fixed, but allowed to vary between periods. Thus, the choice of strategic variable will have no effect on the equilibrium, resulting in the solution being found in an open loop with the escapement level as the strategic variable.

How fishing effort fits into this picture will depend on how effort is defined. We define effort as the product of effort flow and the duration of the flow, and specify two cases: both nations can fish for an equally long time, but one fishes with a greater capacity than the other, or alternatively, one nation has a longer fishing season than the other, but each fishes with the same capacity. The first case, with capacity as the strategic variable, leads to lower net present values and an escapement level lower than that attained when stock size is the strategic variable. The second case, with season length as the strategic variable, leads to net present values and an escapement level slightly lower than that attained if harvest quantity was the strategic variable. A mixture of both strategies is possible, but this becomes too complicated to be attempted here. However, as the strategies pull in opposite directions, we imagine that a combination of both would result in net present values and an escapement level between that of the harvest quantity and the stock size strategies.

Another question relates to decisions being made under uncertainty, which is a very

---

is the dynamic externality (Levhari and Mirman, 1980), and that this result would survive an extension to more general functional forms for the utility and growth functions. Amir and Nannerup noted that the Pareto optimality of the open loop equilibria also holds for certain continuous time formulations of the extraction model; see Chiarrella *et al.* (1984) and Dockner and Kaitala (1989).

important characteristic of the fishery problem (see Sethi *et al.* (2005) for a good analysis of the issues involved). When the movement of the state variable (stock size) is not fully deterministic, but subject to stochastic disturbance, the optimal control must be stated in feedback form, in terms of the state of the system, rather than in terms of time alone (open loop). Owing to the stochastic disturbance, the stock size that will be obtained cannot be known in advance (Kamien and Schwartz, 1992).

Although not dealing with uncertainty, our results show that using the constant capacity as the strategic variable produces the lowest net present value and the lowest escapement level, whereas the fixed harvest quantity strategy has the highest economic value and the highest escapement level. Further, using the escapement level as the strategic variable produces a net present value and escapement level slightly higher than when using the constant capacity as the strategic variable, whereas using the season length as the strategic variable produces a net present value and escapement level slightly lower than with the fixed harvest quantity as the strategic variable. This is when the harvest elasticity with respect to stock size equals one. However, as this elasticity approaches zero, the results change when it comes to the escapement levels. Now, with constant capacity, stock size, and harvest quantity as strategic variables, the escapement levels approach zero, whereas the fixed season length strategy maintains a strictly positive and viable escapement level even when the so-called stock effect is low and the risk of extinction is high. Hence, season length will probably be the safest strategic variable under uncertainty.

Some strategic variables are not easily changed in the short run. For example, much non-resource capital used in the fishery (fleet, processing, human) is not readily shiftable out of the fishery, *i.e.*, non-malleable (Clark *et al.*, 1979). The existence of such non-malleable capital is of substantial significance in real world fisheries management (Bjørndal and Gordon, 2007), and having fishing effort defined as capacity, as opposed to season length, illustrates a case where changing the strategic variable takes time.[7]

---

[7] A fixed harvest quantity might also be justified based on practical problems arising in certain fisheries.

In most cases, pure feedback or open loop strategies, are extremes. In reality, making a decision implies some kind of commitment over a period of time, although, not for all eternity. However, we will not go further in to this but use the open loop solution method to answer our question of how the choice of different strategic variables affect the outcome.

Open loop solutions bring out the difference between the strategic variables, whereas feedback solutions implies that all the strategic variables are easily changed, and that the choice of variable should not have any influence on the solution, resulting in a solution equal to the one obtained in open loop with escapement level as the strategic variable. Moreover, open loop allows us to analyze the effect of rigid strategic variables and the potential implications of choosing one particular variable as the strategic variable over the others. Hence, we will use the open loop solution and look at the stylized case where decisions are made once and for all.

Choosing the harvest quantity as the strategic variable is comparable to Cournot competition (Tirole, 1988).[8] That is to say, each nation, in choosing its current harvest quantity, takes into account the other nation's harvest quantities, as the stock size and growth rate depend on the simultaneous actions of all nations involved in the fishery. Here, Cournot competition is analogous to Cournot oligopoly. The solution in each period is a Cournot solution to the game, but the fish stock responds to the quantity harvested by both nations and there may be a change in the size of the fish stock in future periods (Levhari and Mirman, 1980). Eventually, in the deterministic case, a steady state is attained in which both harvest quantity and the stock size are in an equilibrium.

Limitations and restrictions on transport capacity or processing on shore can be a limiting factor on the amount harvested; the fishermen will not be able to land and sell as much as they would if it was not for these restrictions beyond their control. Example of fisheries where such factors might matter is the Norwegian small coastal fishing boats fishing for saithe, herring, and sprat. The small boats depends on larger vessel to come and collect their catch and bring it to processing plants. Meanwhile, the fishermen have to store the fish alive in net pens and wait for a transport vessel to arrive.

[8] In a game with Bertrand competition, on the other hand, the firms decide on setting the price rather than production. The production capacity is not constrained, and enables the firms to produce any quantity they choose; a price reduction enables them to sell more of their product. The ability for a firm to rapidly change its price in response to its competitors' price setting makes Bertrand competition stronger than Cournot competition (Tirole, 1988).

With the escapement level as the strategic variable, an underlying assumption is that the fishing fleet has a sufficiently large capacity that it is able to reduce the stock size from its initial level to the optimal escapement level in just one period of fishing, *i.e.*, the initial period. The nations' ability to rapidly reduce the stock size, as implied by choosing escapement as the strategic variable, makes the competition between the nations more intense than it would be if the strategic variable were harvest quantity or fishing effort. Stronger competition implies that the stock will be depleted further than it would in a less competitive environment.

The actual control variable used by managers of fisheries need not be the same as the strategic variable used to analyze the problem. Harvest rate and fishing effort are possible control variables, whereas stock size is not. However, using the stock size as a strategic variable does not require that it is the direct control variable (Kaitala, 1986). The desired stock size can be reached by controlling the harvest quantity or fishing effort, *i.e.*, harvest quantity and fishing effort are flexible from one period to another, as opposed to when they are fixed once and for all.

The structure of the chapter is as follows. In Section 1.2, we model a fishery divided between two nations and the problems faced by the nations when stock size, harvest quantity, fishing capacity, or season length, respectively, are chosen as the strategic variable. We numerically solve the model successively for the four strategic variables, and perform a sensitivity analysis in Section 1.3. Finally, in Section 1.4, we conclude the paper.

1.2 The Model

Consider a fish stock where the stock growth depends on the stock size left in the sea after fishing has ceased. That is, the stock size at the beginning of the fishing season (t) is a function of the stock left to grow at the end of the previous season ($t-1$). Ignoring the natural mortality of the fish as long as the fishing season lasts, the seasonal harvest quantity, h_t, will equal the difference between the stock size at the beginning of the season, $X(S_{t-1})$, and the stock size at the end of it, S_t. Taking the price of the harvest landed, p, as given, the per period revenue is:

$$R_t = p[X(S_{t-1}) - S_t]. \tag{1.1}$$

The instantaneous harvest production function will be specified as $h_t = ES_t^b$, where E stands for fishing effort, and S_t is the stock size. The parameter b is the harvest elasticity with respect to the stock size, which takes a value of one if the stock maintains a uniform distribution, and zero if the stock keeps its density constant when harvested. The total cost becomes $C = cE$, where c is a cost parameter. The instantaneous cost per unit harvested is $c_h = \frac{c}{S_t^b}$.

Total harvest costs can now be expressed as follows[9]

$$\begin{aligned} C_t &= c\int_{S_t}^{X(S_{t-1})} u^{-b}du \\ &= \begin{cases} c[\log X(S_{t-1}) - \log S_t] & for \quad b = 1 \\ \frac{c}{1-b}[X(S_{t-1})^{1-b} - S_t^{1-b}] & for \quad 0 < b < 1 \\ c[X(S_{t-1}) - S_t] & for \quad b = 0 \end{cases}, \end{aligned} \tag{1.2}$$

where the case where $0 < b < 1$ is for the intermediate values of the harvest elasticity with respect to the stock size, u denotes the integrand, and log is the natural logarithm, with the number e as the base.

The present value of the profit is:

---

[9] As harvest is $H = X - S$, with X given initially in every period, $S \leq X$, $S = X - H$, $S_H < 0$, and $C(S) = C(S(H))$, and $H = EX$, $S = X(1 - E)$, $S_E = -X$, the properties of the cost function are $C_H = C_S S_H \geq 0$ and $C_{HH} = -C_{SS}S_H = C_{SS} \geq 0$, and $C_E = -C_S S \geq 0$ (where subscripts denote the derivatives).

$$V = \sum_{t=0}^{\infty} (R_t - C_t)\delta^t, \tag{1.3}$$

where $\delta = \frac{1}{1+r}$ is the discount factor, and r is the interest rate.

We let the stock dynamics be described by the discrete variant of the logistic growth function, as follows:

$$X(S) = S + aS[1 - S], \tag{1.4}$$

where a is the intrinsic rate of stock growth. The carrying capacity usually associated with the logistic growth function is set equal to one.

After substituting Equation 1.4 into Equation 1.3, nation i set its control variable, taking the settings of the other nation as fixed. The nations can choose among three possible control variables: the escapement level S^i and $\bar{S}$, the harvest quantity h^i and $\bar{h}$, and the fishing effort E^i and $\bar{E}$, where the bar above Nation Two's controls means that Nation One treats these as constants. We have three objective functions, one for each control variable, that can be maximized with respect to the respective control variable over an infinite planning horizon.

1.2.1 Stock Size

Nation i's problem with respect to the escapement level is:

$$\begin{aligned} \max_{S} \Bigg\{ & p\left[\frac{X_0 - \bar{S}}{2}\right] + p\left[\bar{S} - S\right] - \frac{c}{2}\int_{\bar{S}}^{X_0} u^{-b} du - c\int_{S}^{\bar{S}} u^{-b} du \\ & + \frac{1}{r}\Bigg\{ p\left[\frac{S + aS[1-S] - \bar{S}}{2}\right] + p\left[\bar{S} - S\right] \\ & - \frac{c}{2}\int_{\bar{S}}^{S+aS[1-S]} u^{-b} du - c\int_{S}^{\bar{S}} u^{-b} du \Bigg\}\Bigg\}, \end{aligned} \tag{1.5}$$

with the initial stock size, X_0, given.[10]

We look at a solution where one nation chooses the length of its fishing period, given the length of the other nation's fishing period, and then at a solution where both nations have a fishing period of the same length. This will be the equilibrium solution, given that the nations are identical, *i.e.*, they face the same price and costs.[11] The escapement level, S^*, should be chosen such that it maximizes the net present value of each i's profits over all periods.

The stock size that maximizes nation i's present value of the stock given the other nation's harvest can be found by taking the first derivative of Equation 1.5 with respect to S. We show this and the first-order conditions with respect to harvest quantity and fishing effort in the Appendix.

Both nations' problems are, by the assumption of symmetry, identical.[12] Iteratively finding the optimal escapement level S for one nation, and substituting it as $\bar{S}$ into the other nation's problem, leads to the noncooperative solution $S^* = S = \bar{S}$. The expression for each nation's net present value simplifies to:

$$\begin{aligned} V^i(S^*) &= p\left[\frac{X_0 - S^*}{2}\right] - \frac{c}{2}\int_{S^*}^{X_0} u^{-b}du \\ &+ \frac{1}{r}\left\{p\frac{aS^*[1-S^*]}{2} - \frac{c}{2}\int_{S^*}^{S^*+aS^*[1-S^*]} u^{-b}du\right\}, \qquad i = 1, 2. \end{aligned} \tag{1.6}$$

Both nations take an equal share of the total harvest and make the same profit. However, this is not identical to the nations' objective functions, where each nation continues harvesting under the assumption that the other has stopped and, by unilaterally increasing their catch, makes extra profits. Nation Two does the same as Nation One, so

---

[10] If the initial stock size is less than the optimal stock size, it will be necessary to leave the stock unfished for one or more periods, until $X(S_{t-1}) > S^*$.

[11] As long as identical nations fish simultaneously, they will end up sharing the costs equally.

[12] The focus of this analysis is the choice of strategic variable. The complicating cases of asymmetry in the nations' costs and time preferences are left out. However, Hannesson (1997) analyzed the case where one nation has a lower cost than the others. This could lead the low cost nation to exclude the high cost nations from the fishery altogether.

the final escapement level, S^*, is lower than if the two nations agreed to maximize joint profit, which would be equivalent to maximizing Equation 1.6.

The problem when we choose fishing effort or harvest quantity as the strategic variable follows the same structure as when the escapement level is the strategic variable. The difference is that we need to define the stock levels X, $\bar{S}$, and S as functions of the initial stock size, X_0, and the fishing efforts, E^i and $\bar{E}$ or the harvest quantities, h^i and $\bar{h}$.

1.2.2 Fishing Effort

Effort (E) is the product of effort flow and the duration of the flow, which we refer to as capacity (κ) and season length (τ), respectively. Therefore, $E = \kappa\tau$. Deviations can occur in two ways: (i) both agents fish an equally long time, but one uses greater capacity than the other, or (ii) one agent fishes longer than the other, but with the same capacity. These deviations will not necessarily lead to the same outcome. A mixture of both scenarios is possible, but that becomes very complicated.

For case (i), the present value of profits for agent i is:

$$\max_{E^i_\kappa}\left\{\sum_{t=0}^{\infty}\left\{\frac{E^i_\kappa}{E^i_\kappa+\bar{E}_\kappa}pX_t(S_{t-1})\left[1-e^{-[E^i_\kappa+\bar{E}_\kappa]}\right]-cE^i_\kappa\right\}\delta^t\right\}, \tag{1.7}$$

where $i = 1, 2$, and X_0 is given.

Note that $X\left[1-e^{-[E^i_\kappa+\bar{E}_\kappa]}\right]$ indicates how many fish are taken during the period, but of this amount, agent i gets the share $\frac{E^i_\kappa}{E^i_\kappa+\bar{E}_\kappa}$ if both nations fish equally long, and the total effort is $E^i_\kappa + \bar{E}_\kappa = \int_{S_t}^{X_t(S_{t-1})} u^{-b}du$.[13]

Under case (ii), the present value of profits for agent i is:

---

[13] For $0 < b < 1$, total effort is $\frac{X_t(S_{t-1})^{1-b}-S_t^{1-b}}{1-b}$, and $E^i_\kappa + \bar{E}_\kappa$ is proportional to total effort by some factor, say, 1. Thus, we can write $\frac{X_t(S_{t-1})^{1-b}-S_t^{1-b}}{1-b} = E^i_\kappa + \bar{E}_\kappa$. Rearranging this expression, we obtain the following:

$$S_t = \left[X_t(s_{t-1})^{1-b} - \left[1-b\right]\left[E^i_\kappa + \bar{E}_\kappa\right]\right]^{\frac{1}{1-b}}.$$

$$\begin{aligned}\max_{E_\tau^i}\Bigg\{\sum_{t=0}^{\infty}\Bigg\{&p\frac{X_t(S_{t-1})}{2}\left[1-e^{-\bar{E}_\tau}\right]-c\frac{\bar{E}_\tau}{2}\\&+pX_t(S_{t-1})e^{-\bar{E}_\tau}\left[1-e^{-[E_\tau^i-\bar{E}_\tau/2]}\right]-c[E_\tau^i-\bar{E}_\tau/2]\Bigg\}\delta^t\Bigg\},\end{aligned}\tag{1.8}$$

where $i=1,2$, and X_0 is given.

When season length is the strategic variable the intermediate stock size, $\bar{S}$, is expressed as $X_t(S_{t-1})e^{-\bar{E}_\tau}$, where $\bar{E}_\tau=\int_{\bar{S}}^{X_t(S_{t-1})}u^{-b}du$ is the total intermediary fishing effort when both nations harvest simultaneously. Whereas $E_\tau^i=\int_{S_t}^{\bar{S}}u^{-b}du$ is the fishing effort used when nation i extend its fishing season unilaterally. The escapement level of period t is $S_t=X_te^{-[\bar{E}_\tau+E_\tau^i]}$, and the stock size when fishing starts in the next period is $X_t(S_{t-1})=S_{t-1}+aS_{t-1}[1-S_{t-1}]$. This goes on until an escapement level is reached where the harvest quantity and the stock size are in equilibrium.[14]

Having found E_j^*, $j=\kappa,\tau$, we can substitute this into the objective functions with respect to fishing effort, and the net present value of the fishery for nation i becomes:

$$\begin{aligned}V^i(E_j^*)=p&\frac{X_0}{2}\left[1-e^{-[\int_{S_t}^{X_0}u^{-b}du]}\right]-\frac{c}{2}\int_{S_0}^{X_0}u^{-b}du\\&+\sum_{t=0}^{\infty}\Bigg\{\Bigg\{p\frac{X_t(S_{t-1})}{2}\left[1-e^{-[\int_{S_t}^{X_t(S_{t-1})}u^{-b}du]}\right]-\frac{c}{2}\int_{S_t}^{X_t(S_{t-1})}u^{-b}du\Bigg\}\delta^t\Bigg\},\end{aligned}\tag{1.9}$$

where $i=1,2$, $j=\kappa,\tau$, and X_0 is given.

1.2.3 Harvest Quantity

Considering harvest quantity as the strategic variable we assume that the fishing effort is fixed and equal for both nations, and that they face the same price, costs and technology.

---

[14] Denote the time period when equilibrium is reached by T. Then $X_T(S_{T-1})e^{-2E_\tau^*}=S^*$ is the equilibrium stock size, which in this case maximizes the net present value. However, before S^* is reached there are several Ss that maximize the present value.

Both nations harvest will be equal as long as they fish simultaneously for the same amount of time. Then the only way for a nation to harvest more (less) than the other is by extending (shorten) its fishing season relative to the other. Hence, we have to apply the same solution method as with escapement level and season length (fishing effort case (*ii*)) as the strategic variable to find the equilibrium solution.[15]

The problem of nation i with respect to the harvest quantity is now:

$$\max_{h^i}\left\{\sum_{t=0}^{\infty}\left\{ph^i-\frac{c}{2}\int_{X_t(S_{t-1})-2\bar{h}}^{X_t(S_{t-1})}u^{-b}du-c\int_{S_t}^{X_t(S_{t-1})-2\bar{h}}u^{-b}du\right\}\delta^t\right\}, \tag{1.10}$$

where X_0 is given, and $i=1,2$.

When the optimal harvest quantity, $h^*=h^i=\bar{h}$, $i=1,2$, is found and substituted into, say, Nation One's problem, an expression of the nation's net present value simplifies to:

$$V^i(h^*)=ph^*-\frac{c}{2}\int_{X_0-2h^*}^{X_0}u^{-b}du+\sum_{t=1}^{\infty}\left\{\left\{ph^*-\frac{c}{2}\int_{X_t(S_{t-1})-2h^*}^{X_t(S_{t-1})}u^{-b}du\right\}\delta^t\right\}, i=1,2. \tag{1.11}$$

Note that this is not the nation's objective function, but a result of the fact that with the assumption of symmetry, the nations end up choosing the same harvest quantity in equilibrium. Equation 1.11 is the resulting net present value function when the nations have solved the noncooperative game.

Having defined the problem with respect to stock size, harvest quantity, and fishing effort, we are able to find numerical solutions to the strategic variables and compare the resulting stock sizes remaining after fishing has stopped and the net present values of the fishery for the four strategic variables in question.

---

[15] When harvest quantity is the strategic variable the intermediate stock size, $\bar{S}$, is expressed as $X-2\bar{h}$. $2\bar{h}$ is the total intermediary harvest quantity when both nations harvest simultaneously. The escapement level of the initial period is $S_0=X_0-h_0^i-\bar{h}$, and the stock size when fishing starts in the next period is $X_1=S_0+aS_0[1-S_0]$.

Table 1.1: The benchmark parameters of the model

Parameter	**Initial stock**	**Growth rate**	**Price**	**Costs**	**Discount rate**
Symbol	X_0	a	p	c	r
Value	1	1	1	0.5	0.05

1.3 Results

In this section, we present the numerical solutions of the problems presented in the previous section. We start by choosing some values of the parameters: price, the initial stock size, the intrinsic rate of stock growth, costs, and the discount rate. We will refer to these parameters as the benchmark set. The benchmark values are shown in Table 1.1.

By setting the price, p, equal to one, we measure the value of the fish in the same units as the stock size. An initial stock size, X_0, equal to one means that the stock is in pristine condition when the fishery starts in the initial period. Growth differs from one population to another, and this affects the harvest. In order to account for this, we will perform a sensitivity analysis where we solve the models for values of the intrinsic growth rate between one and 0.10. We will also present sensitivity analyses of the interest rate, r, and the cost parameter, c.

1.3.1 Reference Solutions

Table 1.2 reports the results from the numerical solutions of the models using the benchmark parameter values in Table 1.1, where the harvest elasticity with respect to the stock size, b, takes the values 1 and 0.1. The variables S, E^i_j, and h^i, $i = 1, 2$, and $j = \kappa, \tau$, are the respective strategic variables of each model satisfying the first-order necessary conditions. The NPVs are the net present values found by substituting the respective optimal, noncooperative values of the strategic variables into Equations 1.6, 1.11, and 1.9. The harvest quantities are the equilibrium harvest quantities.

Table 1.2: Noncooperative solution: net present values for the strategic variables escapement level, fishing effort, and harvest quantity, using the benchmark values in Table 1.1

	Variables	NPV	Escapement level	Harvest quantity	Fishing effort
b = 1.00	S	0.778	0.592	0.121	-
	E^i_κ	0.773	0.582	0.122	0.175
	E^i_τ	0.819	0.619	0.118	0.162
	h^i	0.831	0.632	0.116	-
b = 0.10	S	0.435	0.065	0.003	-
	E^i_κ	1.265	0.000	> MSY	0.132
	E^i_τ	1.221	0.344	0.113	0.252
	h^i	1.263	0.000	> 0.125	-

From Table 1.2, for the case where $b = 1$, we see that selecting the constant capacity, E_κ, as the strategic variable in the game produces the lowest net present value and the lowest escapement level of the four variables, followed by the constant escapement strategy S. The constant harvest quantity strategy, h, has the highest economic value, as well as the highest escapement level. The fixed season length strategy, E_τ, has the second largest NPV and escapement level.

For the case where $b = 0.1$, the order of the net present values and the escapement levels are changed relative to when $b = 1$. The constant capacity strategy has the highest NPV, and the harvest quantity strategy has the second highest. Although the net present values are higher than when $b = 1$, the harvest rates, for both the harvest quantity strategy and the constant capacity strategy, are above the maximum sustainable yield (MSY).[16] Continually harvesting more than the MSY will eventually lead to the stock's extinction.

The NPV of the season length strategy is now less than those of the harvest quantity and constant capacity strategies, but is higher than the NPV when $b = 1$. However,

---

[16] The MSY is $\max_S\{aS[1-S]\}$, which is satisfied for S_{MSY} equal to 0.5, giving an MSY of 0.25 for an intrinsic growth rate, a, equal to one. The harvest quantity strategy, reported in the lower panel of Table 1.2, is only marginally larger than the MSY, and the associated net present value is only marginally larger than the NPV produced if the harvest rate was identical to the MSY.

the escapement level remains well above the stock size where price equals costs. The escapement strategy's NPV is now reduced relative to when $b = 1$, and the corresponding escapement level is very low, close to zero.

As the harvest elasticity with respect to stock size approaches zero, the strategies of a fixed escapement level, a fixed harvest rate, or a constant capacity all make the stock vulnerable to extinction. However, the constant fishing season length strategy turns out to be the most conservative strategy when the harvest elasticity approaches zero, with a relatively high escapement level and a profitable, sustainable fishery. This is in accordance with the results found by Vincent (1981), namely, that an adjustment of the harvest level may be necessary in order to prevent extinction.

For comparison, Table 1.3 present the results from the sole-owner case, where the nations cooperate on maximizing the joint profit, which is equivalent to maximizing Equation (1.3) with escapement level, S, fishing effort, E,[17] or harvest quantity, h, as the alternative strategic variables.[18] Note that the NPV, the harvest quantity, and the fishing effort reported are half of the total value, the total harvest, and the total effort as they are shared equally between the two nations. This is done to make the comparison between a noncooperative management (Table 1.2) and a cooperative management (Table 1.3) easier.

If the resource is managed as a sole-owner property and joint long-term profits are maximized, the fixed escapement strategy[19] is the most profitable as well as the most conservative strategy with respect to the escapement level. The constant harvest quantity strategy, on the other hand, is the least profitable and is less conservative than the other strategies. This result, which is true for both $b = 1$ and $b = 0.1$, is the opposite of the

---

[17] When a sole owner manages the stock, the NPV and the escapement level are the same regardless of how fishing effort is defined, *i.e.*, regardless of whether there is a constant capacity E_κ or a constant fishing season length E_τ. Hence, the fishing effort reported in Table 1.3 is actually E_τ.

[18] The sole owner optimization is carried out by deciding on the level of the strategic variable and keeping it fixed over the entire planning horizon, assuming a pristine stock size initially. Thus, the results from the optimization will depend on the choice of strategic variable.

[19] Reed (1979) found a policy of maintaining a constant escapement level to be optimal in the presence of growth uncertainty.

Table 1.3: Sole-owner (cooperative) solution: net present values for the strategic variables escapement level, fishing effort, and harvest quantity, using the benchmark values in Table 1.1

	Variables	NPV	Escapement level	Harvest quantity	Fishing effort
b = 1.00	S	0.852	0.683	0.108	-
	E	0.849	0.679	0.109	0.139
	h	0.846	0.677	0.109	-
b = 0.10	S	1.310	0.498	0.125	-
	E	1.301	0.485	0.1249	0.170
	h	1.263	0.000	> 0.125	-

result that we obtained under a noncooperative management.

The relatively low NPV found under noncooperative management with the escapement level as the strategic variable may seem somewhat surprising; reaching the steady state after only one period from a pristine stock means that the profit earned in the initial period is high. In contrast, the equilibrium stock size is reached after 38 periods for the harvest quantity strategy, and after about 20 periods with constant capacity and season length as strategic variables (for $b = 1$). We can think of the harvest rate and fishing effort as control variables that put constraints on our decision making, which is locked in by a constant harvest or effort. Profits in every period, except the initial one, are discounted, and even with a high initial profit, the net present value from the game played with stock size as the strategic variable is the lowest of the three possible strategic variables.

A comparison between the initial profits from choosing the harvest rate (or the season length) as the strategic variable, setting $b = 1$, and the initial profit from the game where stock size is the strategic variable, shows that the initial profit is 69% (79%) of the escapement strategy's initial profit for the harvest rate and season length strategies, respectively. However, from period one onwards, the escapement strategy's profit is more than halved, relative to its initial profit. For the harvest rate and season length strategies, on the other hand, the reduction in each period's profits is less pronounced and, after a few periods, the harvest rate strategy has the highest per period profit. Thus, even though stock size as a strategic variable yields a high initial profit, the strong competition implied when stock size is chosen as the strategic variable in the game forces the nations to reduce the stock size to such a low level that the initial gain is offset by the future losses from having to fish the stock at a low level. As the stock size is reduced, the cost of harvesting goes up at an increasing rate. If we are free to choose the optimal levels, a fixed harvest rate or a fixed season length, as opposed to choosing a fixed stock size, does not necessarily mean that we are worse off.

Table 1.2 also shows that the constant capacity stock size strategies have the lowest escapement levels and the highest harvest rates in equilibrium. Selecting harvest quantity as the strategic variable, on the other hand, produces the highest escapement level and the lowest equilibrium harvest rate. Selecting a constant fishing season length as the strategic variable results in an intermediate escapement level, and an intermediate equilibrium harvest rate relative to the results for constant capacity, stock size, and harvest rate. However, the results are not significantly different from the results obtained when the harvest rate is selected as the strategic variable.

If we modeled fishing effort as a mixture of both capacity and time, we can imagine that the two factors would work in opposite directions; capacity tends towards lower NPVs and a lower escapement level, whereas time will lead to higher NPVs and a higher escapement level. The combination of both will probably result in intermediate NPVs and an intermediate escapement level relative to the results when stock size and harvest quantity are selected as strategic variables.

1.3.2 Sensitivity Analysis

As a value of the intrinsic rate of stock growth, a, equal to one is somewhat high for most of the economically important fish stock, it is appropriate to perform a sensitivity analysis. Moreover, the benchmark values of the discount rate and harvest costs, 0.05 and

0.5, respectively, were chosen without any justification in the literature or from empirical evidence and thus also warrant sensitivity analyses. We report the escapement levels and the net present values from using, respectively, stock size, harvest rate, and fishing effort as the strategic variable, while changing the value of one parameter at a time and holding the other parameters at the benchmark values reported in Table 1.1, and keeping the harvest elasticity with respect to the stock size equal to one.

As Table 1.4 shows, the results were robust for the net present values. The effects of changing the parameter values can be summarized in the following way: the net present values were reduced and tended to converge for all strategic variables when the growth rate was lowered, or when the discount rate and the costs were increased. The natural resource conservation outcome, on the other hand, was reversed for low intrinsic growth rates and discount rates.

Starting with the benchmark value of the intrinsic growth rate and gradually reducing it initially raised the escapement levels of the constant capacity, and season length, and harvest quantity strategies, which reached their respective maxima at about 0.60, 0.95, and 0.85. Thereafter, their escapement levels gradually declined, all having reached the stock size where price equals costs at a growth rate of 0.10. However, the escapement level of the stock size strategy declined continuously as the growth rate was lowered, but remained well above the stock size where price equals costs, even at low rates of stock growth.

The escapement levels of all four strategic variables are reduced by increasing the discount rates. However, they decline at different rates. The harvest quantity strategy with the highest escapement level in the benchmark case has the highest rate of decrease, reaching a stock size where price equals costs at a discount rate of about 0.30, along with the constant capacity strategy. The stock size strategy, on the other hand, is the variable least sensitive to discount rates, resulting in the highest escapement level at higher rates of discount.

Table 1.4: Summary of the sensitivity analysis

		Net present values				Escapement levels			
Parameter	Values	S	E_κ	E_τ	H	S	E_κ	E_τ	H
Growth rate, a	1.00	0.778	0.773	0.819	0.831	0.592	0.582	0.619	0.632
	0.95	0.728	0.728	0.771	0.783	0.591	0.583	0.623	0.632
	0.85	0.631	0.641	0.677	0.689	0.588	0.586	0.619	0.633
	0.60	0.408	0.437	0.459	0.468	0,577	0.589	0.615	0.630
	0.30	0.186	0.220	0.228	0.233	0.551	0.569	0.587	0.591
	0.28	0.174	0.207	0.214	0.219	0.548	0.565	0.582	0.579
	0.25	0.157	0.187	0.193	0.198	0.545	0.557	0.574	0.560
	0.20	0.131	0.154	0.159	0.165	0.537	0.537	0.555	0.516
	0.15	0.109	0.123	0.127	0.133	0.529	0.503	0.529	0.500
	0.10	0.092	0.100	0.098	0.097	0.521	0.500	0.500	0.500
Discount rate, r	0.10	0.422	0.413	0.439	0.444	0.588	0.562	0.604	0.612
	0.15	0.303	0.293	0.313	0.316	0.583	0.542	0.589	0.589
	0.18	0.264	0.253	0.271	0.273	0.581	0.530	0.580	0.564
	0.20	0.244	0.233	0.250	0.251	0.580	0.522	0.575	0.559
	0.30	0.186	0.178	0.188	0.189	0.573	0.500	0.548	0.500
Cost, c	0.30	1.255	1.374	1.436	1.484	0.430	0.460	0.496	0.534
	0.40	1.022	1.057	1.113	1.139	0.513	0.520	0.556	0.580
	0.60	0.543	0.524	0.560	0.564	0.669	0.648	0.684	0.690
	0.70	0.335	0.315	0.330	0.340	0.745	0.718	0.752	0.755
	0.80	0.164	0.153	0.165	0.165	0.824	0.800	0.826	0.827
	0.90	0.046	0.045	0.046	0.046	0.907	0.900	0.908	0.908

1.4 Conclusions

In a competitive environment, the constant capacity and fixed escapement strategies are the least profitable and have the lowest escapement levels. The constant harvest quantity, on the other hand, is now the strategy that has the highest net present value and the highest escapement level. The net present values and the escapement levels are lower with noncooperation than with full cooperation.

By dividing fishing effort into two components, capacity and fishing season length, a striking difference between these two measures of effort appears. Controlling the fishing effort by setting the fishing season length, assuming that the nations fish with equal capacity, resulted in net present values and an escapement level almost as high as when the harvest quantity strategy was used. On the other hand, assuming the duration of the fishing season is equal for both nations but allowing for differences in fishing capacity resulted in the lowest net present values and escapement level of all four possible strategic variables. Indeed, the net present values and escapement level were even lower than those for the stock size strategy, which we initially anticipated would give the lowest net present values and escapement level.

In this paper, we have examined the open loop solutions where harvest/stock size/effort are fixed over an infinite time horizon. This means that we are committed to the decisions made regarding our strategy. Harvest quantity, the length of the fishing season, and to some extent the escapement level, can easily be changed, even in the short run. However, the fishing capacity can only be changed in the longer run. It takes time to accommodate a reduction or increases in the number of fishing vessels, the vessels' size, storage capacity, and so on. Hence, our future actions, bounded by our present choice of capacity, will lead to depletion of the resource and loss of potential economic rents. Although one might argue that controlling effort consists of setting both capacity and time, each works in opposite directions, and combining these strategies yields an outcome set that is intermediate to the cases of harvest quantity and stock size. Nevertheless, it is still interesting to note that the most rigid of the variables is the most competitive one.

The assumptions about the distribution of fish in the sea, associated with the fish stock's response to being harvested, are crucial. As the tendency to a uniform distribution is reduced and the harvest elasticity with respect to the stock size approaches zero, the stock becomes more vulnerable to extinction. At stock elasticities close to zero, a season length strategy is the only strategic variable that sustains a profitable stock size in the long run.

The effects of the choice of strategic variable are to some extent sensitive to the level of the intrinsic growth rate and discounting. At lower growth rates, the fixed escapement strategy becomes the strategy with the highest escapement level, whereas the escapement levels for harvest quantity, constant capacity, and season length strategies tend towards the stock size level where price equals costs. In addition, a high discount rate increases the escapement strategy's escapement level relative to the other strategies.

References

AMIR, R., AND N. NANNERUP (2006): "Information Structure and the Tragedy of the Commons in Resource Extraction," *Journal of Bioeconomics*, 8(2), 147–165.

BJØRNDAL, T., AND D. V. GORDON (2007): "On the Contributions of Professor G.R. Munro to Economics," in *Advances in Fisheries Economics: Festschrift in Honour of Professor Gordon R. Munro*, ed. by T. Bjørndal, D. V. Gordon, R. Arnason, and U. R. Sumaila, chap. 1, pp. 1–14. Blackwell Publishing Ltd, Oxford, UK.

CHIARRELLA, C., M. KEMP, N. V. LONG, AND K. OKUGUCHI (1984): "On the Economics of International Fisheries," *International Economic Review*, 25(1), 85–92.

CLARK, C. W. (1980): "Restricted Access to Common-Property Fishery Resources: A Game-Theoretic Analysis," in *Dynamic Optimization and Mathematical Economics*, ed. by P.-T. Liu, chap. 7, pp. 117–132. Plenum Press, New York.

CLARK, C. W., F. H. CLARKE, AND G. R. MUNRO (1979): “The Optimal Management of Renewable Resource Stocks: Problems of Irreversible Investment,” *Econometrica*, 47(1), 25–47.

DOCKNER, E. J., AND V. KAITALA (1989): “On Efficient Equilibrium Solutions in Dynamic Games of Resource Management,” *Resources and Energy*, 11, 23–34.

ESWARAN, M., AND T. LEWIS (1985): “Exhaustible Resources and Alternative Equilibrium Concept,” *Canadian Journal of Economics*, 18(3), 459–473.

FUDENBERG, D., AND J. TIROLE (1991): *Game Theory.* The MIT Press, Cambridge, Massachusetts.

HÄMÄLÄINEN, R. P., AND V. KAITALA (1982): “A Game on the Choice of Policy Variables in a Dynamic Resource Management Game,” in *Proceedings of the 21st IEEE Conference on Decision and Control, Orlando, Florida, December 8-10, 1982*, pp. 181–185, New York. IEEE Control Systems Society, IEEE.

HANNESSON, R. (1997): “Fishing as a Supergame,” *Journal of Enviromental Economics and Management*, 32, 309–322.

KAITALA, V. (1986): “Game Theory Models of Fisheries Management - A Survey,” in *Dynamic Games and Applications in Economics*, ed. by T. Basar, chap. 10, pp. 252–266. Springer Verlag, Berlin.

KAMIEN, M. I., AND N. L. SCHWARTZ (1992): *Dynamic Optimization: The Calculus of Variations and Optimal Control in Economics and Management.* Elsevier, Amsterdam, 2 edn.

LEVHARI, D., AND L. J. MIRMAN (1980): “The Great Fish War: An example using a Dynamic Cournot-Nash Solution,” *Bell Journal of Economics*, 11, 322–344.

MAY, R. M., J. R. BEDDINGTON, C. W. CLARK, S. J. HOLT, AND R. M. LAWS (1979): “Management of Multispecies Fisheries,” *Science*, 205(4403), 267–277.

Reed, W. J. (1979): "Optimal Escapement Levels in Stochastic and Deterministic Harvesting Models," *Journal of Environmental Economics and Management*, 6, 350–363.

Reinganum, J. F., and N. L. Stokey (1985): "Oligopoly Extraction of a Common Property Natural Resource: The Importance of the Period of Commitment in Dynamic Games," *International Economic Review*, 26(1), 161–173.

Sethi, G., C. Costello, A. Fisher, M. Haneman, and L. Karp (2005): "Fishery management under multiple uncertainty," *Journal of Environmental Economics and Management*, 50, 300–318.

Tirole, J. (1988): *The Theory of Industrial Organization.* The MIT Press, Cambridge, Massachusetts.

Vincent, T. L. (1981): "Vulnerability of a Prey-Predator Model under Harvesting," in *Renewable Resource Management. Proceedings of a Workshop on Control Theory Applied to Renewable Resource Management and Ecology in Christchurch, New Zealand, January 7-11, 1980*, ed. by T. L. Vincent, and J. M. Skowronski, pp. 112–132, Berlin, Heidelberg, New York. Springer Verlag.

Appendix

This shows the solution of the first-order necessary conditions for the problems in Equations (1.5), (1.7), (1.8), and (1.10) for $b = 1$.

The escapement level, S, should be chosen such that it maximizes the net present value of profits over all periods. The first-order necessary condition for this is:

$$-p + \frac{c}{S} + \frac{1}{r}\left\{ p\left[\frac{1 + a(1-2S}{2})\right] - p - \frac{c\left[1 + a(1-2S)\right]}{2\left[S + aS(1-S)\right]} + \frac{c}{S}\right\} = 0. \tag{A1}$$

Equation (A1) can be solved for S which equals the optimal escapement level S^*, independently of the initial stock size X_0, and the intermediate stock size $\bar{S}$.

The first-order necessary conditions with fishing effort or harvest quantity as the strategic variable are functions of the initial stock size, X_0, and the other nation's fishing effort $\bar{E}_j$, $j = \kappa, \tau$, or harvest quantity, $\bar{h}$. In addition, the time at which the stock size reaches its steady state, $t \geq T$, depends on the strategic variable.

Fishing effort, case(i):

By denoting i's share, $\frac{E^i_\kappa}{E^i_\kappa + \bar{E}_\kappa}$ as α_1, and the other nation's share, $1 - \frac{E^i_\kappa}{E^i_\kappa + \bar{E}_\kappa}$, as α_2, and using the fact that $H_t = X_t \left[1 - e^{-[E^i_\kappa + \bar{E}_\kappa]}\right]$ and $S_t = X_t e^{-[E^i_\kappa + \bar{E}_\kappa]}$, we can simplify the first-order necessary conditions to:

$$\sum_{t=0}^{\infty} \left\{ \frac{\alpha_2}{E^i_\kappa + \bar{E}_\kappa} pH_t + \alpha_1 pS_t - c + \alpha_1 pX'_t(S_{t-1}) \frac{dS_{t-1}}{dE^i_\kappa} \right\} \delta^t = 0, i = 1, 2. \tag{A2.i}$$

Fishing effort, case(ii):

By recognizing that $S_t = X_t e^{-[E^i_\tau + \bar{E}_\tau/2]}$, the first-order condition can be simplified to:

$$\sum_{t=0}^{\infty} \left\{ \left\{ pS_t - c + pX'_t(S_{t-1}) \left[\left[\frac{1 + e^{-\bar{E}_\tau}}{2} \right] - e^{-[E^i_\tau + \bar{E}_\tau/2]} \right] \frac{dS_{t-1}}{dE^i_\tau} \right\} \delta^t \right\} = 0, i = 1, 2. \tag{A2.ii}$$

The first-order necessary condition with respect to the harvest quantity is:

$$\sum_{t=0}^{\infty} \left\{ \left\{ p - \frac{c}{S_t} + \frac{cX'_t(S_{t-1})}{2} \left[\frac{2}{S_t} - \frac{1}{X_t} - \frac{1}{X_t - 2\bar{h}} \right] \frac{dS_{t-1}}{dh^i} \right\} \delta^t \right\} = 0, \tag{A3}$$

where $i = 1, 2$, X_0 is given, and the prime denotes the first derivative with respect to S_{t-1}.

From period T onwards, the stock size, S_T, is in equilibrium and all the expressions in Equations (A2.i), (A2.ii), and (A3) can be treated as constants, for all $t \geq T$. The marginal benefits and costs terms are clearly constant for all $t \geq T$, and $\sum_{t=T}^{\infty} \delta^t$, which is the sum of an infinite geometric series and, thus, converges to $\frac{\delta^T}{1-\delta}$.

Chapter 2

The Blue Whiting Coalition Game

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.

2.1 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,

---

[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 chapter is organized as follows. Section 2.2 describes the development of the blue whiting fishery and management. Section 2.3 outlines an age structured bioeconomic model of the fishery. In Section 2.4, we discuss the games and the rules of the game and define some fundamental concepts regarding stability. In Section 2.5, the game is applied to the blue whiting fishery. Finally, Section 2.6 concludes.

2.2 The Blue Whiting Fishery and 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.

2.2.1 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 (4.1) names important places in relation to the blue whiting, and later Figure (2.3) 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 (2.2)). 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 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

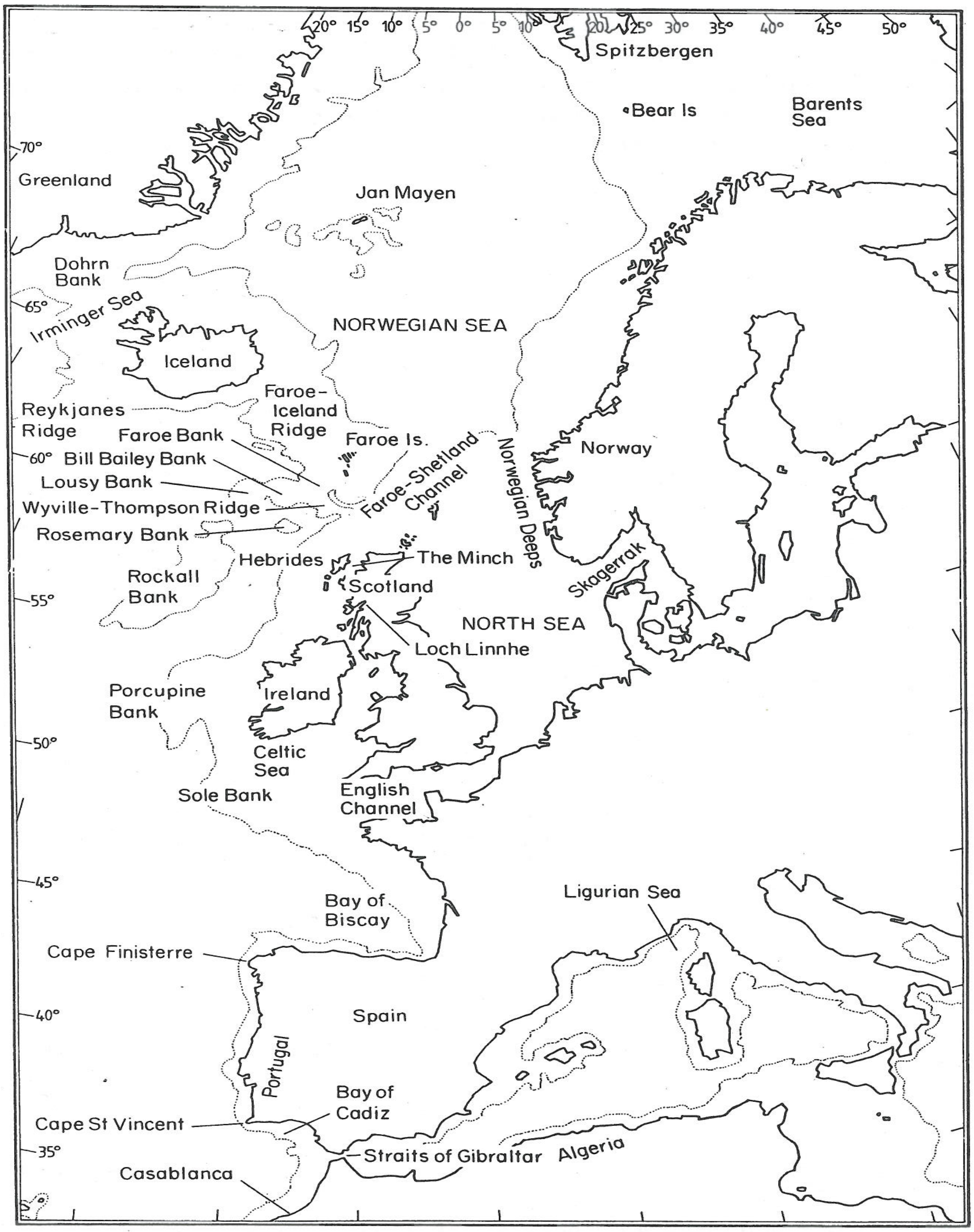

Figure 2.1: Map showing the Northeast Atlantic and adjacent waters (Bailey, 1982).

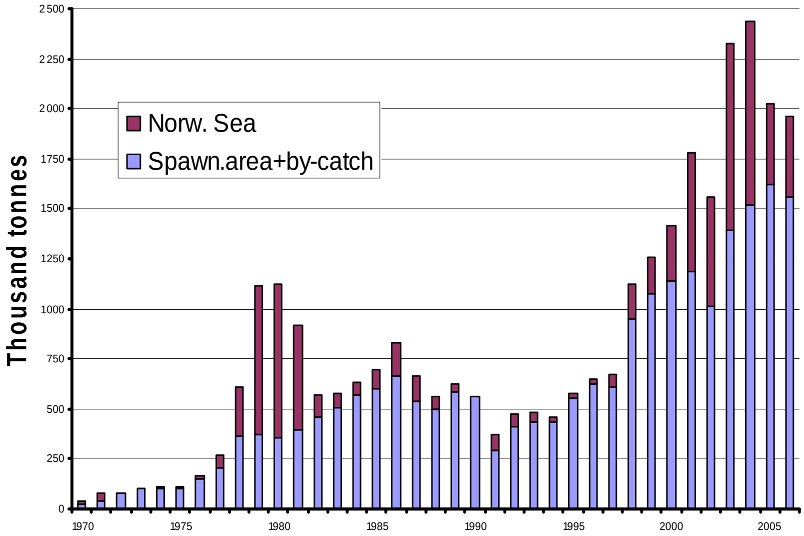

Figure 2.2: Landings from the main fisheries, 1970-2006 (adjusted from Monstad (2004)).

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 recommended by ICES (ICES, 2003).

---

[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.

2.2.2 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].

2.3 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.

2.3.1 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

---

[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.

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, 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

Table 2.1: 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

migration back to the spawning grounds. This results in a uniform age distribution equal to one. The catchability coefficients are shown in Table (2.1). Note that the $q_{a,y}$s distribute the overall fishing effort across the different age groups.

2.3.2 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 (2.2), 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

$$SSB_t = \sum_{a=1}^{10+} MO_a W_a N_{a,t}. \tag{2.1}$$

where W_a is the individual weight in kilograms at age a (ICES, 2007), shown in Table (2.2), and $N_{a,t}$ is number of individuals in age group a in year t.

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 (2.2) and Ricker (2.3) (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

Table 2.2: Blue whiting: proportion of maturation, weight at age, and numbers at age 2000-2006.

Age	Proportion		Number of fish[†]						
group	mature	Weight[‡]	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

in Tables (2.3) and (2.4), 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.

$$R_t = \frac{\alpha \times SSB_{t-1}}{\beta + SSB_{t-1}} \tag{2.2}$$

$$R_t = SSB_{t-1} \times \exp\left(\alpha(1 - SSB_{t-1}/\beta)\right) \tag{2.3}$$

Running this serially correlated recruitment process, starting from any initial recruitment level, the recruitment will converge to a certain recruitment level given the

Table 2.3: 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 2.4: 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.

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 (2.5) 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

$$R_t = \begin{cases} 500, & if \quad SSB_{t-1} < B_{lim} \\ \alpha, & if \quad B_{lim} \leq SSB_{t-1} < B_{pa} \\ \alpha + \beta \times R_{t-1}, & otherwise. \end{cases} \tag{2.4}$$

The parameter values in Equation (2.4) are shown in Table (2.5).

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,

---

[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).

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 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

Table 2.5: 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	

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 (2.3) (cf. Figure (4.1)), 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 (2.6) 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 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.

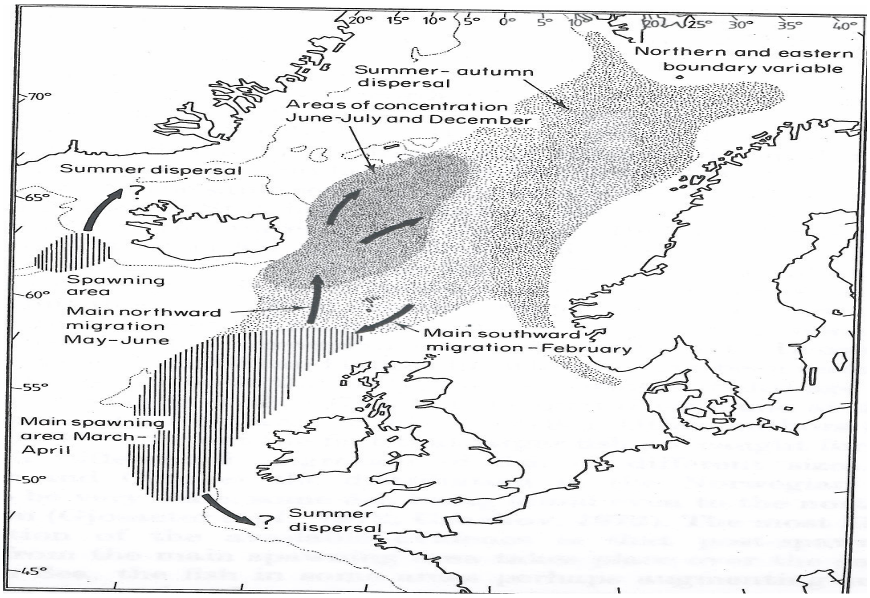

Figure 2.3: Map summarizing the migration pattern and areas of concentration of adult blue whiting (Bailey, 1982).

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.

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

Table 2.6: 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

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)

$$\begin{aligned} N_{a,y} =& N_{a,y-1}\Bigg\{ S_{NEAFC,y-1} e^{-[m/4+q_{a,y-1}\sum_i X_i]} \\ & + \sum_j S_{j,y-1} e^{-[m/4+q_{a,y-1}X_j]} \Bigg\}, \end{aligned} \tag{2.5}$$

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 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 2000-2006 were caught in the NEAFC regulatory areas.

In order to validate the model and the parameter values presented in Tables (2.1),

Table 2.7: Validation of the model.[†]

		Fleets					
Year		EU	FO	IS	NO	RU	Total
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.

(2.2) and (2.6) 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 (2.7).

The fleets are allowed to fish within their nation's EEZ and in international waters. The efforts presented in Table (2.7) 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.

2.3.3 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)

$$\begin{aligned}\pi_{i,y} =& pX_i \sum_{a=1}^{10+} q_{a,y} N_{a,y} w_a \left[\frac{S_{j,y}(1 - e^{-[m/4 + q_{a,y}X_i]})}{m/4 + q_{a,y}X_i} + \frac{S_{NEAFC,y}(1 - e^{-[m/4 + q_{a,y}\sum_i X_i]})}{m/4 + q_{a,y}\sum_i X_i} \right] \\ & - c_i X_i,\end{aligned} \tag{2.6}$$

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 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

Table 2.8: 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.

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 (2.8).

2.4 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.

2.4.1 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

---

[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).

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 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

---

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

[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.

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 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).

2.4.2 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:

$$\begin{aligned} &\exists S, C \quad and \quad C' \in \Omega : \\ &\qquad S \subset C \quad and \quad S \subset C', \quad C \neq C' \quad and \quad V(S, C) \neq V(S, C') \end{aligned}$$

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.

2.5 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 (2.9) 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 (2.8) 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. 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

---

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

Table 2.9: 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.

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 (2.9) 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 (2.9), 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.

2.5.1 Partition Function

From the payoffs presented in Table (2.9), 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.

$$V^*(C_{CS}, C_{CS}) = 3,494.8 - 1,558.3 = NOK \quad 1,936.5 \quad million \tag{2.7}$$

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

Table 2.10: 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.

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

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

Table (2.10) clearly shows that positive externalities do exist in this game:

$$\begin{aligned} & V(EU, \{(FO, IS, NO), (EU), (RU)\}) = 0.48 \\ > & \left\{ \begin{array}{l} V(EU, \{(FO, IS), (EU), (NO), (RU)\}) = -0.28 \\ V(EU, \{(FO, NO), (EU), (IS), (RU)\}) = -0.10, \end{array} \right. \end{aligned}$$

$$\begin{aligned} & V(FO, \{(EU, IS, NO), (FO), (RU)\}) = 0.68 \\ > & \left\{ \begin{array}{l} V(FO, \{(EU, IS), (FO), (NO), (RU)\}) = 0.34 \\ V(FO, \{(EU, NO), (FO), (IS), (RU)\}) = 0.35 \\ V(FO, \{(IS, NO), (EU), (FO), (RU)\}) = -0.14, \end{array} \right. \end{aligned}$$

$$\begin{aligned} & V(IS, \{(EU, FO, NO), (IS), (RU)\}) = 0.50 \\ > & \left\{ \begin{array}{l} V(IS, \{(EU, FO), (IS), (NO), (RU)\}) = 0.06 \\ V(IS, \{(FO, NO), (EU), (IS), (RU)\}) = -0.03 \\ V(IS, \{(EU, NO), (EU), (FO), (RU)\}) = -0.10, \end{array} \right. \end{aligned}$$

and

$$\begin{aligned} & V(NO, \{(EU, FO, IS), (NO), (RU)\}) = 0.53 \\ > & \left\{ \begin{array}{l} V(NO, \{(EU, IS), (FO), (NO), (RU)\}) = -0.05 \\ V(NO, \{(FO, IS), (EU), (NO), (RU)\}) = 0.21 \\ V(NO, \{(EU, FO), (IS), (NO), (RU)\}) = 0.00. \end{array} \right. \end{aligned}$$

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 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 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.

Table 2.11: Sensitivity analysis.

	Stand-Alone Stability							
	Initial		Discount		Cost parameters			
	Year		Rate		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.

2.5.2 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 (2.11) reports the results of this. For comparison, the results in the last column of Table (2.10) 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 (2.11), 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.

2.5.3 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 (2.7), 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.

2.6 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.

References

ANON. (1982): “United Nations Convention on the Law of the Seas,” United Nations Document A/Conf.62/122.

——— (1995): “United Nations Conference on Straddling Fish Stock and Highly Migratory Fish Stocks. Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Seas of 10 December 1982 Relating to the Conservation and Management of Straddling Fish Stocks and Higly Migratory Fish Stocks,” UN Doc. A/Conf./164/37.

——— (2005): “Agreed Record of Conclusion of Fisheries Consultations on the Management of the Blue Whiting Stock in the North-East Atlantic,” an agreement between the blue whiting coastal states consisting of the EU, Denmark, on behalf of the Faroe Islands, Iceland, and Norway, December 2005.

——— (2006): “Om dei fiskeriavtalane Noreg har ingått med land for 2006 og fisket etter avtalane i 2004 og 2005,” Stortingsmelding nr. 22, 2005–2006, Det Kongelege Fiskeri- og Kystdepartementet (The Norwegian Ministry of Fisheries and Coastal Affairs).

ARNASON, R., G. MAGNUSSON, AND S. AGNARSSON (2001): “The Norwegian Spring-spawning Herring Fishery: A Stylized Game Model,” *Marine Resource Economics*, 15, 293–319.

BAILEY, R. S. (1982): “The Population Biology of Blue Whiting in the North Atlantic,” *Advances in Marine Biology*, 19, 257–355.

BJØRNDAL, T. (2008): “Overview, Roles, and Performance of the North East Atlantic Fisheries Commission (NEAFC),” SNF working paper series. Institute for Research in Economics and Business Adminstration (SNF), Bergen, Norway.

BJØRNDAL, T., AND G. R. MUNRO (2003): “The Management of High Seas Fisheries Resources and the Implementation of the UN Fish Stocks Agreement of 1995,” in *The*

International Yearbook of Environmental and Resource Economics 2003-2004, ed. by H. Folmer, and T. Tietenberg, New Horizons in Environmental Economics, chap. 1, pp. 1–35. Edward Elgar, Cheltenham, UK.

Brasão, A., C. C. Duarte, and M. A. Cunha-e-Sá (2001): "Managing the Northern Atlantic Bluefin Tuna Fisheries: The Stability of the UN Fish Stock Agreement Solution," *Marine Resource Economics*, 15(4), 341–360.

Burton, P. S. (2003): "Community Enforcement of Fisheries Effort Restrictions," *Journal of Environmental Economics and Management*, 45(2), 474–491.

Clark, C. W. (1990): *Mathematical Bioeconomics: The Optimal Management of Renewable Resources.* John Wiley & Sons, Inc., New York Chichester Brisbane Toronto Singapore, 2 edn.

Duarte, C. C., A. Brasão, and P. Pintassilgo (2000): "Management of the Northern Atlantic Bluefin Tuna: An Application of C-Games," *Marine Resource Economics*, 15, 21–36.

Ekerhovd, N.-A. (2003): "Spelet om kolmule," SNF Report 34/03. Center for Fisheries Economics, Institute for Research in Economics and Business Administration (SNF), Bergen, Norway.

——— (2007): "Individual Vessel Quotas and Unregulated Species: The Norwegian Blue Whiting Fishery," NHH Discussion Paper SAM 05/07.

Hart, S., and M. Kurz (1983): "Endogenous Formation of Coalitions," *Econometrica*, 51(4), 1047–64.

Hátún, H., J. A. Jacobsen, and A. B. Sandø (2007): "Environmental influence on the spawning distribution and migration of northern blue whiting (*Micromesistius poutassou*)," Discussion Paper ICES CM/B:06, International Council for the Exploration of the Seas Northern Pelagic Working Group.

HEINO, M. (2006): "Blue whiting - the stock collapse that never came," in Iversen, P. Fossum, H. Gjøsæter, M. Skogen and R. Toresen (eds.) 2006. Havets ressurser og miljø 2006. Fisken og havet, særnr. 1-2006. Institute of Marine Research. Bergen, Norway.

HILLBORN, R., AND C. J. WALTERS (1992): *Quantative Fisheries Stock Assessment - Choice, Dynamics and Uncertainty.* Chapman and Hall, New York; London, UK.

ICES (1995): "Report of the Blue Whiting Working Group, Vigo, Spain, 8-14 September 1994," ICES CM 1995/Assess:7, Copenhagen.

——— (1998): "Report of the Northern Pelagic and Blue Whiting Fisheries Working Group," ICES CM 1998/ACFM:18.

——— (2002): "Report of the Study Group on the Further Development of the Precautionary Approach to Fishery Management," ICES CM 2002/ACFM:10. Ref. ACE,D.

——— (2003): "Report of the Northern Pelagic and Blue Whiting Working Group," ICES CM 2003/ACFM:23.

——— (2005): "Report of the Northern Pelagic and Blue Whiting Fisheries Working Group," ICES CM 2006/ACFM:05, Copenhagen.

——— (2007): "Report of the Northern Pelagic and Blue Whiting Working Group, 2007," International Council for the Exploration of the Seas (ICES), Advisory Committee on Fishery Management, CM 2007/ACFM:29, Copenhagen.

KAITALA, V., AND M. LINDROOS (1998): "Sharing the Benefits of Cooperation in High Seas Fisheries: A Characteristic Function Game Approach," *Natural Resource Modeling*, 11(4), 275–299.

LINDROOS, M. (2004a): "Restricted Coalitions in the Management of Regional Fisheries Organizations," *Natural Resource Modeling*, 17, 45–70.

——— (2004b): “Sharing the Benefits of Cooperation in the Norwegian Spring-spawning Herring Fishery,” *International Game Theory Review*, 6(1), 35–53.

Lindroos, M., and V. Kaitala (2001): “Nash Equilibria in a Coalition Game of the Norwegian Spring-spawning Herring Fishery,” *Marine Resource Economics*, 15, 321–339.

Lindroos, M., V. Kaitala, and L. G. Kronbak (2007): “Coalition Games in Fisheries Economics,” in *Advances in Fisheries Economics: Festschrift in Honour of Professor Gordon Munro*, ed. by T. Bjørndal, D. V. Gordon, R. Arnason, and U. R. Sumaila, chap. 11, pp. 184–195. Blackwell Publishing, Oxford, UK.

Monstad, T. (2004): “Blue Whiting,” in *The Norwegian Sea Ecosystem*, ed. by H. R. Skjoldal, chap. 9, pp. 263–288. Tapir Academic Press, Trondheim, Norway.

Munro, G. R. (1979): “The Optimal Management of Transboundary Renewable Resources,” *Canadian Journal of Economics*, 3, 271–296.

Pálsson, Ó. K. (2005): “An analysis of by-catch in the Icelandic blue whiting fishery,” *Fisheries Research*, 73, 135–146.

Pintassilgo, P. (2003): “A Coalition Approach to the Management of High Seas Fisheries in the Presence of Externalities,” *Natural Resource Modeling*, 16(2), 175–197.

Pintassilgo, P., and M. Lindroos (2008): “Application of partition function games to the management of straddling fish stocks,” in *Game Theory and Policymaking in Natural Resources and the Environment*, ed. by A. Dinar, J. Albiac, and J. Sánchez-Soriano, Routledge Explorations in Environmental Economics, chap. 4, pp. 65–84. Routledge, London; New York.

Schaefer, M. B. (1957): “Some considerations of population dynamics and economics in relation to the management of marine species,” *Journal of the Fisheries Research Board of Canada*, 14, 669–681.

STANDAL, D. (2006): “The rise and decline of blue whiting fisheries - capacity expansion and future regulations,” *Marine Policy*, 30, 315–327.

YI, S.-S. (1997): “Stable Coalitons with Externalities,” *Games and Economic Behavior*, 20, 201–237.

——— (2003): “Endogenous formation of economic coalitions: A survey of the partition function approach,” in *The Endogenous Formation of Economic Coalitions*, ed. by C. Carraro, The Fondazione Eni Enrico Mattei (FEEM) Series on Economics and the Environment, chap. 3, pp. 80–127. Edward Elgar, Cheltenham, UK; Northhampton, MA, USA.

Chapter 3

Climate Change and the Blue Whiting Agreement

Abstract

This paper investigates the formation, stability and success of an agreement between the coastal states on the management of the blue whiting fishery under two opposing assumption about the distribution of the stock, based on different climate change scenarios for the Northeast Atlantic Ocean as a result of global warming. Two climate change scenarios for the Northeast Atlantic Ocean are analysed. In one scenario, increased ocean temperature expands the blue whiting's migration pattern and its area of distribution, making Russia a coastal state with regard to the blue whiting stock in addition to the countries already recognized as such. In this scenario, the stability of the coastal state coalition does not change relative to the *Status Quo*, *i.e.*, Ekerhovd (2008), although the payoff to the coalition increases when Russia enters. The second scenario looks at the consequences of a colder climate on the distribution of the blue whiting stock. The stock no longer occupies Russian EEZs and Russia is not regarded as a coastal state by the other countries. In this scenario, the stability of the coastal state coalition is severely weakened such that the formation of a coastal state coalition is an even more unlikely outcome compared to Ekerhovd (2008).

Keywords: Straddling fish stocks, coastal state coalition agreement, cooperation, climate change, blue whiting.

JEL Classification: Q22, Q28, Q54, C72.

3.1 Introduction

The ecosystem of the Norwegian Sea and the Barents Sea is one of the world's richest, purest, and most productive marine areas, and where the climate, both in the sea and the atmosphere, is expected to change[1] in response to global warming (Stenevik and Sundby, 2007). Although the prevailing view seems to be that these waters will become warmer over the next 50-70 years, to the extent that the Arctic Ocean could become ice-free during the summer, there is also the possibility that the Gulf Stream and the termohaline circulation could be weakened, leading to a colder climate in northwestern Europe, despite global warming (Anon., 2004).

Higher ocean temperatures could lead to higher plankton production and, because of ice melting, even production in previously inaccessible areas. Changes in prey availability will influence the distribution of straddling fish stocks[2] which seasonally migrate into such areas. Furthermore, higher abundance of plankton could lead to an increased production of plankton feeding fish, and as plankton feeding fish typically serve as important prey for other fishes, this could spill over on the higher trophic levels as well. However, the predator-prey relationship makes it difficult to predict how exactly these changes will affect a specific species, and is further complicated by the fact that individuals of the same species may be at different trophic levels depending on the current stage of their life cycle. Younger and smaller fish, to a large extent, feed on plankton, but as they become older and bigger they prefer larger organisms as prey; and even smaller individuals of their own species.

The blue whiting stock[3] (*Micromesistius Poutassou* Risso) in the Northeast Atlantic

---

[1] Climate change is usually linked to changes in temperature, but also other climate parameters such as salinity, ocean currents, ice conditions, light (which depends, among other things, on the cloud cover and season), and turbulence (which changes with the wind conditions) affects the ecosystem (Anon., 2008).

[2] 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 (Bjørndal and Munro, 2003).

[3] The northern stock of blue whiting migrates between the spawning grounds west of the British Isles

migrates through the exclusive economic zones (EEZs) of the European Union (EU), the Faroe Islands, Iceland, and Norway, considered as the coastal states with respect to the stock, and in the international waters beyond the EEZs, where it can be harvested by vessels from any country, not just the coastal states. Besides the coastal states, Russia is an important player in the blue whiting fishery. In 2005, the coastal states consisting of the EU, the Faroe Islands, Iceland, and Norway signed an agreement starting in 2006 which includes a long term management strategy that implies annual reductions in the landings until the management goals are reached. Russia will be accommodated by transfers from some of the coastal states and additional catches in the North East Atlantic Fisheries Commissions' (NEAFC)[4] regulatory areas, *i.e.*, the international waters in the Northeast Atlantic (Ekerhovd, 2008).

The blue whiting stock is expected to change its distribution, spawning areas and migration pattern due to climate change. Recently, in years with a relatively warm ocean climate, juvenile blue whiting has appeared in great abundance in the southwesterly parts of the Barents Sea. Currently, the blue whiting stock's main spawning area is west of the British Isles, but some spawning takes place along the coast of Norway as well as in the Norwegian fjords. The northerly distribution of blue whiting might also be an effect of stock abundance caused by the successful recruitment in the 1996-2004 period. The poor recruitment after this period, along with a high fishing mortality, has led to considerable reduction in the blue whiting abundance in the Barents Sea in 2007, even though the temperature was well above its long term mean. This means that the distribution of the

---

and the feeding areas in the Norwegian Sea, cf. Figure (4.1). After the spawning period in March-May, the majority of the post-spawning fish pass the Faroe Islands either on the western side through the Faroe Bank Channel or on the eastern side through the Faroe-Shetland Channel. The stock size of the blue whiting has fluctuated substantially during the last three decades, and is currently estimated to be high, at approximately four million tonnes (Bailey, 1982; ICES, 2007). For more details about the blue whiting fishery, see Ekerhovd (2008).

[4] The North East Atlantic Fisheries Commission, NEAFC, is a regional fisheries management organization, with membership open to all parties with real interests in the fish stocks within the areas covered by the convention. NEAFC is intended to serve as a forum for consultation, the exchange of information on fish stocks and the management of these, and advise on the fisheries in the high sea areas mentioned in the convention on which the commission is based. Since most of the fisheries take place 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).

species is also connected with the abundance of the stock.

This paper investigates the formation, stability and success of an agreement between the coastal states on the management of the blue whiting fishery under two opposing assumptions about the distribution of the stock, based on different climate change scenarios for the Northeast Atlantic Ocean as a result of global warming. Because the EEZs are fixed upon the map, an expansion of the blue whiting stock could affect the distribution of the stock between the EEZs of the coastal states and international waters. These changes could put the coastal state agreement under strain. Some of the coastal states might be discontented with their share of the stock, based on an earlier distribution of the stock, so that they find themselves better off leaving the coalition of coastal states and harvesting the stock taking the others' actions as given. The expansion of the distribution area could make Russia a coastal state, demanding the same status and same rights as the original coastal state coalition members.

Two climate change scenarios for the Northeast Atlantic Ocean are analysed. In one scenario, increased ocean temperature expands the blue whiting's migration pattern and its area of distribution, making Russia a coastal state with regard to the blue whiting stock in addition to the countries already recognized as such. In this scenario, the stability of the coastal state coalition does not change relative to the *Status Quo*, *i.e.*, Ekerhovd (2008), although the payoff to the coalition increases when Russia enters. The second scenario looks at the consequences of a colder climate on the distribution of the blue whiting stock. The stock no longer occupies Russian EEZs and Russia is not regarded as a coastal state by the other countries. In this scenario, the stability of the coastal state coalition is severely weakened such that the formation of a coastal state coalition is an even more unlikely outcome compared to Ekerhovd (2008).

The analysis is conducted, drawing on the model described in Ekerhovd (2008), by changing the quarterly zonal attachment shares of the blue whiting stock in accordance with the climate change scenarios outlined in the previous paragraph.

The chapter is organized as follows. Section 3.2 describes the climate change scenarios and how we imagine this will affect the distribution of the blue whiting stock. In Section 3.3 we presents results of the blue whiting game by applying the distributions derived in the previous section. Finally, Section 3.4 sums up the results and concludes.

3.2 Climate Change Scenarios

In this section we outline two alternative scenarios regarding climate change in the Norwegian Sea and the Barents Sea. An increased inflow of Atlantic water into these areas causing the ocean temperatures to rise is described first. Then the opposite outcome of global warming on the ocean temperatures in the Northeast Atlantic, with a reduced inflow of Atlantic water to the Norwegian Sea and the Barents Sea, is outlined. Finally, we describe how we imagine the blue whiting stock will be distributed geographically under the respective climatic regimes. These distributions will later be used when we simulate the coalition payoffs under the different climate change scenarios.

The two climate change scenarios are linked to fluctuations in the North Atlantic Oscillation index. The North Atlantic Oscillation (NAO) is a large scale oscillatory fluctuation of atmospheric mass between the Icelandic low-pressure centre and the Azores' high-pressure ridge that normally extends from continental Europe to the Azores. It is manifested by a weakening of the intensity in one of the centres of action and a simultaneous strengthening in the other. The NAO index is determined from the difference in atmospheric sea level pressure between the Azores high and the Iceland low, for example between Lisbon, Portugal, and Stykkisholmur, Iceland. It is seen most clearly from December to March, when the atmospheric circulation is most intense. Variability in the NAO is associated with the strength of the westerly winds across the North Atlantic into the Nordic Seas. A high NAO winter index is associated with the path of the low pressures along a "pressure trough" that extends from the Iceland low, across the Norwegian and Barents Seas, to the margins of Siberia (Blindheim, 2004). A high NAO index is associated with high inflow of Atlantic water, while the opposite is true for a low

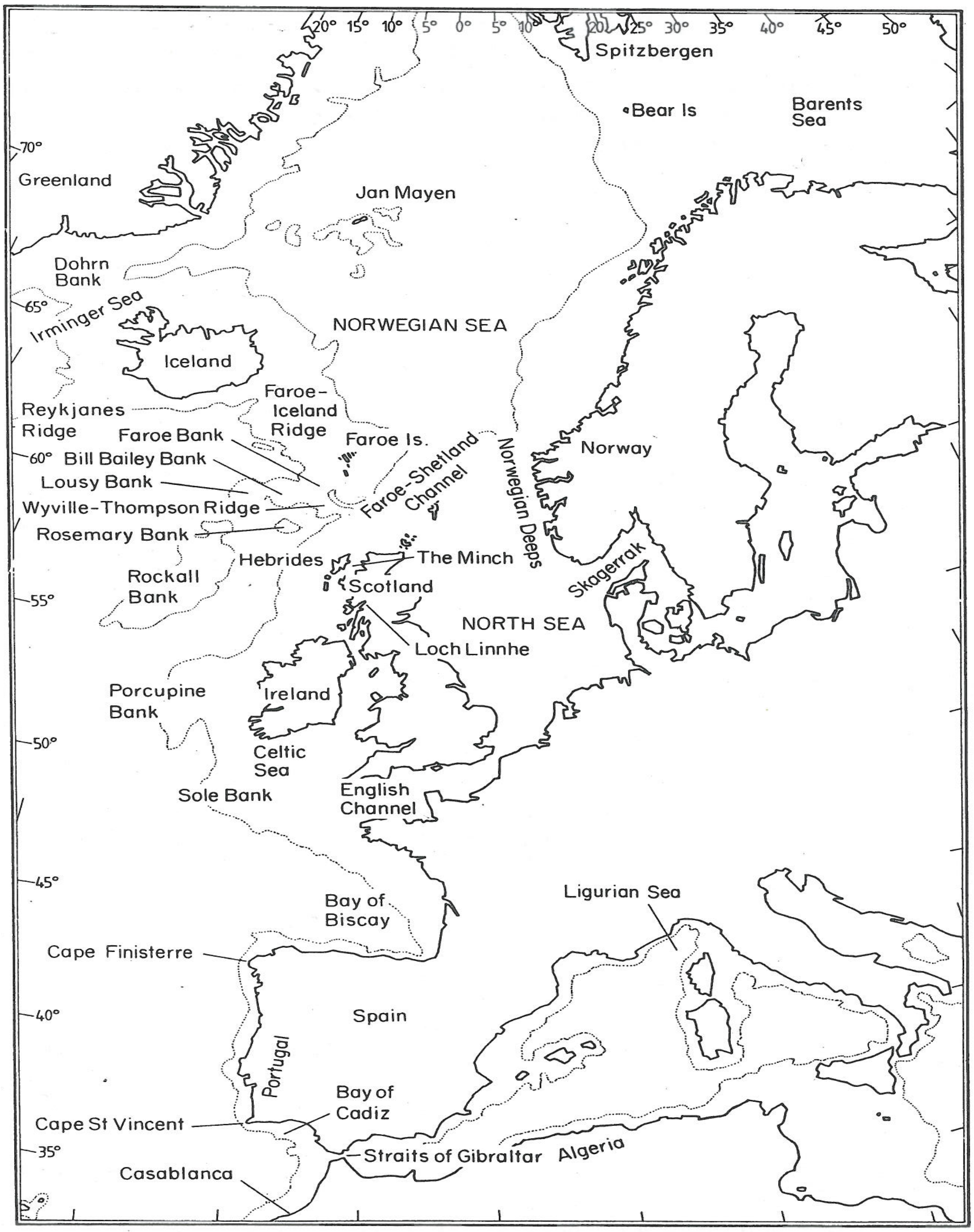

Figure 3.1: Map showing the Northeast Atlantic and adjacent waters (Bailey, 1982).

NAO index (Stenevik and Sundby, 2007; Hátún *et al.*, 2007).

3.2.1 Scenario 1. High NAO, high inflow of Atlantic water and higher temperatures in the Barents Sea

The blue whiting is one of the species that will probably expand its distribution in a more northerly direction in response to a warmer ocean climate. Recently, in years with relatively warm ocean climate, juvenile blue whiting has appeared in great abundance in the south-western part of the Barents Sea. The blue whiting stock's main spawning area is currently west of the British Isles, but some spawning activity occurs off the coast of Norway as well as in the Norwegian fjords. With spawning occurring in the Norwegian Sea and adolescent blue whiting growing up in the Norwegian Sea and the Barents Sea, the blue whiting would be able to take advantage of the production of plankton in the Greenland Sea in a warmer ocean climate (Anon., 2008).

A more northerly distribution of blue whiting may also be caused by the increased stock abundance due to an exceptionally high recruitment to the stock during the 1996-2004 period. The poor recruitment in the following years, combined with a high fishing pressure, led to a significant reduction in the abundance of blue whiting in the Barents Sea in 2007, even though the temperature was well above the long term mean. This indicates that the distribution of fish species also is linked to the over-all stock abundance (Anon., 2008).

This scenario is associated with a high NAO index, and a high inflow of Atlantic water into the Norwegian Sea and the Barents Sea accompanied by an increase in temperature (Stenevik and Sundby, 2007). Following an increase in inflow of Atlantic water and a resulting increase in temperature, the character of the ecosystems in Norwegian waters will most likely change. The borders between the temperate ecosystem in the Atlantic and the boreal ecosystems of the Norwegian Sea/Barents Sea and the Arctic areas may move northwards, resulting in substantial changes to the fish communities in the different areas.

3.2.2 Scenario 2. Low NAO, less inflow of Atlantic water

With a reduced NAO index, on the other hand, the inflow of Atlantic water will become weaker but broader (Stenevik and Sundby, 2007). This could lead to increased temperature in the western part of the Norwegian Sea and changes in the migration and spawning distribution of the blue whiting.

During a phase of negative NAO index, the inflow of Atlantic water to the Barents Sea is reduced. This leads to a colder climate, particularly in the southern part of the Barents Sea. Also, the abundance of the copepode *Calanus finmarchicus*, an important zooplankton prey for blue whiting, decreases due to less inflow.

After spawning, blue whiting migrate from the spawning grounds west of the British Isles, past the Faroe Islands and into the feeding areas in the Norwegian Sea during the spring months March to early June. The changeable migratory route through Faroese waters, as inferred from fisheries statistics, is found to be closely linked to the hydrography along the Rockall Bank, as simulated by an ocean circulation model (Hátún *et al.*, 2007). Furthermore, Hátún *et al.* (2007) suggests a variable spawning intensity around the bank as the causal mechanism for this link. The observed variability is primarily governed by the strength and extent of the subpolar gyre[5] (Hátún *et al.*, 2005). The blue whiting is especially sensitive to both temperature and salinity during the spawning period and will

---

[5] Wind stress induces a circulation pattern that is similar for each ocean. In each case, the wind-driven circulation is divided into large gyres that stretch across the entire ocean: subtropical gyres extend from the equatorial current system to the maximum westerlies in a wind field near 50° latitude, and subpolar gyres extend poleward of the maximum westerlies. The subpolar gyres are cyclonic circulation features. In the North Atlantic the subpolar gyre consists of the North Atlantic Current on the equatorward side and the Norwegian Current that carries relatively warm water northward along the coast of Norway. The heat released from the Norwegian Current into the atmosphere maintains a moderate climate in northern Europe. Along the east coast of Greenland is the southward-flowing cold East Greenland Current. It loops around the southern tip of Greenland and continues flowing into the Labrador Sea. The southward flow that continues off the coast of Canada is called the Labrador Current. This current separates for the most part from the coast near Newfoundland to complete the subpolar gyre of the North Atlantic. Some of the cold water of the Labrador Current, however, extends farther south. Source: "ocean." Encyclopædia Britannica. 2008. Encyclopædia Britannica Online. 07 Jul. 2008 <http://www.britannica.com/EBchecked/topic/424285/ocean>.

only spawn in waters warmer than 8-9° C and salinities in excess of 35.2-3. The average hydrography in the region east of the Rockall Bank is near these threshold values, although the variations are considerable.

After the spawning period in March - May, the majority of the post-spawning fish pass the Faroe Islands either on the western side through the Faroe Bank Channel or on the eastern side through the Faroe-Shetland Channel, cf. Figure (4.1).

When the fishery takes place on the western slope of the Faroe Plateau the fishable concentrations are confined to a narrow and often dense band along the shelf edge which also is associated with a sharp hydrographic front. When, on the other hand, the fishery takes place in the Faroe-Shetland Channel the shoals are more dispersed and less fishable.

High values of the gyre index are associated with cold and fresh conditions in the Northeast Atlantic. This seems to coincide with years when the stock has an easterly distribution, while low gyre index values, associated with warm and saline conditions, seem to coincide with years when the stock has a western distribution.

The NAO index is directly related to the westerlies through the sea level pressure difference between Iceland and the Azores-Gibraltar region. This index showed record high values during the early 1990s. This resulted in a relatively fresh, strong and inflated subpolar gyre, and the subarctic front was moved far eastwards into the Northeast Atlantic. The spawning/migration waters between Rockall Bank and the Faroe Islands were fresh and cold during these years, and the blue whiting stock was small.

An extreme reversal in the NAO index in the winter 1995-1996 was followed by a dramatic decline in the subpolar gyre, a westward shift in the subarctic front, a temperature and salinity increase in the spawning/migration region, replacement in the plankton community[6], a threefold increase in the blue whiting spawning stock biomass, and a clear shift from years with a persistent easterly migration route to a period of a

---

[6] Prior to 1996, an inverse relationship between the abundance of *Calanus finmarchicus* and NAO winter index appeared to exist. However, with the change to the strongly negative NAO index in 1996, when the regression predicted high abundance of *Calanus*, there was in fact a record low abundance. Low abundance continued for the rest of the 1990s (Skjoldal and Sætre, 2004).

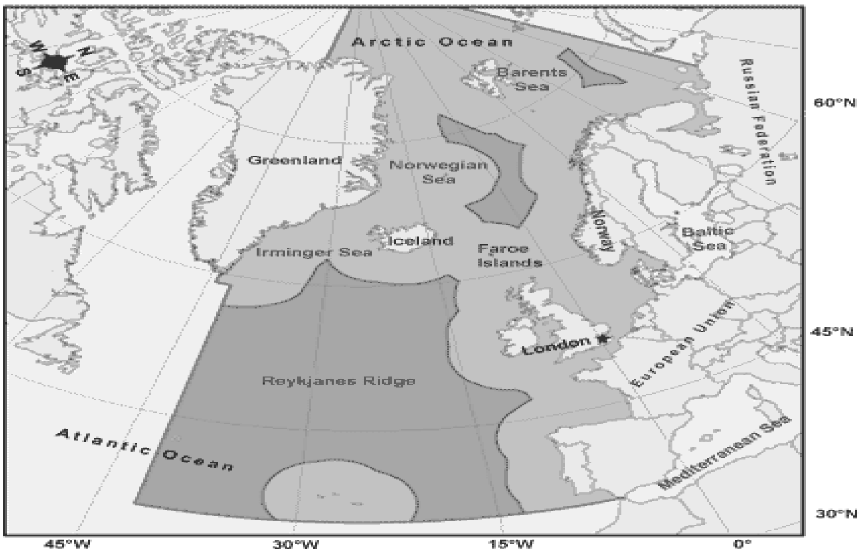

Figure 3.2: The high seas of the NEAFC Regulatory Area (dark shaded) inside the NEAFC Convention Area (shaded) in the Northeast Atlantic http://www.neafc.org/about/ra.htm

persistent western migration.

Under a climate regime with a reduction in the NAO index and less inflow of Atlantic water, the distribution of the blue whiting stock will move in a south-western direction, with no blue whiting in Russia's exclusive economic zone (EEZ) and no spawning activity in Norwegian waters. However, with an increased density of blue whiting on the banks between Iceland and the Faroe Island, spawning activity in Icelandic waters is possible.

3.2.3 Distribution of the Blue Whiting Stock

In the following, we will illustrate the above scenarios by suggesting a quarterly area distribution for each of them that is consistent with the implied spawning and migration patterns.

The year is divided into quarters, y, whereas i denotes the respective EEZs in the case of the EU, Faroe Islands, Iceland, Norway and Russia, and NEAFC regulatory area (RA)[7] meaning international waters, shown in Figure (3.2). Thus, $S_{i,y}$ denotes the shares

---

[7] There are three regulatory areas within the NEAFC convention area. In the the Northeast, and of

of the blue whiting stock available for harvest in the different waters throughout the year. Typically, each scenario is not characterized by a single combination of shares. Several combinations are possible and each scenario is defined by a sub-group of all possible combinations. Therefore, three alternative combinations of shares are presented for each scenario.

First, Table (3.1) shows the shares, $S_{i,y}$, in the case where there is an increase in the amount of Atlantic water entering the Norwegian Sea, causing an increase in sea water temperature and salinity in both the Norwegian Sea and the Barents Sea. This means that the habitat of the blue whiting expands north-eastward into the Barents Sea, such that Russia becomes a coastal state, and the blue whiting spawns in Norwegian waters in addition to EU and Faroese waters. At times when the blue whiting is not present in a coastal state's EEZ, the fishermen from that country can only fish blue whiting in international waters if possible[8]. Otherwise, they can harvest in their home waters as well as on the high seas.

The year begins with blue whiting present in all areas except for Russia's EEZ. Spawning takes place in the second quarter, and the stock is equally divided between EU, Faroese and Norwegian EEZs (Scenario 1a, and 1b), or alternatively between EU, Faroese, Icelandic and Norwegian EEZs (Scenario 1c). After spawning, the stock migrates out into the Norwegian Sea and the Barents Sea, abandoning EU waters altogether, with either 1/3 of the stock in international waters and 1/3 in the Norwegian EEZ (Scenario 1a) or, as in Scenario 1b, with 1/4 of the stock in international waters and 1/4 in the Norwegian EEZ; the rest is equally divided between the EEZs of Iceland, the Faroe Islands

---

minor relevance in the blue whiting context, the 'Loop Hole', a 67,100 km^2 area in the Barents Sea, surrounded by the EEZs of Norway and Russia, and the fishery protection zone around the Svalbard archipelago (Spitzbergen); in the Norwegian Sea, the 321,700 km^2 area, known as the 'Banana Hole', surrounded by the EEZs of Norway, Iceland, the Faroe Islands and Greenland, the fishery zone around Jan Mayen, an island under Norwegian sovereignty, and the fishery protection zone around Svalbard; and finally, the area in the Northeast Atlantic with the Reykjanes Ridge in the centre, c.f Figure (3.2), which is limited to the north by the EEZs of Greenland, Iceland and the Faroe Islands, and to the east by the EEZ of the EU (Bjørndal, 2008).

[8] This is a simplification that we make. In reality, bilateral agreements exist allowing foreign vessels access to the stock in national waters.

Table 3.1: Scenario 1: Quarterly zonal attachment of the blue whiting stock $S_{i,y}$

Scenario 1a				
$i\backslash y$	First quarter	Second quarter	Third quarter	Fourth quarter
NEAFC RA	1/3	0	1/3	1/3
European Community	1/3	1/3	0	0
Faroe Islands	1/9	1/3	1/9	1/9
Iceland	1/9	0	1/9	1/9
Norway	1/9	1/3	1/3	1/3
Russian Federation	0	0	1/9	1/9
Scenario 1b				
$i\backslash y$	First quarter	Second quarter	Third quarter	Fourth quarter
NEAFC RA	1/2	0	1/4	1/4
European Community	1/8	1/3	0	0
Faroe Islands	1/8	1/3	1/6	1/6
Iceland	1/8	0	1/6	1/6
Norway	1/8	1/3	1/4	1/4
Russian Federation	0	0	1/6	1/6
Scenario 1c				
$i\backslash y$	First quarter	Second quarter	Third quarter	Fourth quarter
NEAFC RA	1/4	0	1/5	1/5
European Community	1/4	1/4	0	0
Faroe Islands	1/6	1/4	1/5	1/5
Iceland	1/6	1/4	1/5	1/5
Norway	1/6	1/4	1/5	1/5
Russian Federation	0	0	1/5	1/5

Table 3.2: Scenario 2: Quarterly zonal attachment of the blue whiting stock $S_{i,y}$

Scenario 2a				
$i\backslash y$	First quarter	Second quarter	Third quarter	Fourth quarter
NEAFC RA	1/2	0	1/6	1/6
European Community	1/2	1/2	0	0
Faroe Islands	0	1/4	1/3	1/3
Iceland	0	1/4	1/3	1/3
Norway	0	0	1/6	1/6
Russian Federation	0	0	0	0
Scenario 2b				
$i\backslash y$	First quarter	Second quarter	Third quarter	Fourth quarter
NEAFC RA	1/2	0	1/4	1/4
European Community	1/2	1/2	0	0
Faroe Islands	0	1/4	9/32	9/32
Iceland	0	1/4	9/32	9/32
Norway	0	0	3/16	3/16
Russian Federation	0	0	0	0
Scenario 2c				
$i\backslash y$	First quarter	Second quarter	Third quarter	Fourth quarter
NEAFC RA	1/2	0	1/4	1/4
European Community	1/2	1/4	0	0
Faroe Islands	0	1/4	1/4	1/4
Iceland	0	1/4	1/4	1/4
Norway	0	1/4	1/4	1/4
Russian Federation	0	0	0	0

and Russia in the third and fourth quarters. In Scenario 1c, the stock is equally divided between the NEAFC regulatory area and the EEZs of the Faroe Islands, Iceland, Norway, and Russia in the third and fourth quarters.

As to Scenario 2, Table (3.2) shows the quarterly distribution of the blue whiting stock in national and international waters when the penetration of Atlantic water into the Norwegian/Barents Seas is reduced because of less wind-induced ocean currents. This means colder sea water with reduced salinity, in spite of global warming, and a more western distribution of the blue whiting stock in the Norwegian Sea. Spawning takes place in the waters between Iceland and the Faroe Islands as well as in EU waters. The western distribution reduces the availability of the blue whiting in international waters and Norwegian waters, and Russia is no longer regarded as a coastal state.

During the first quarter the stock is equally divided between the North East Atlantic Fisheries (NEAFC) regulatory area in Northeast Atlantic and EU waters west of the British Isles and Ireland. Spawning takes place in the second quarter, in EU waters (1/2) and in national waters between Iceland and the Faroe Islands (1/4 each). In Scenario 2c, we allow for spawning in the Norwegian EEZ, as well as in the EEZs of the EU, the Faroe Islands and Iceland, and the stock is equally divided between the zones. During summer and autumn the blue whiting migrates into the Norwegian Sea, but because of colder and fresher water in the eastern part, along the coast of Norway, it now has a more western distribution, with highest densities in the EEZs of Iceland and the Faroe Islands. This means that there will be no blue whiting in Russia's EEZ, only in the NEAFC regulatory area in the Norwegian Sea and the EEZs of the Faroe Islands, Iceland, and Norway. For the respective scenarios and shares we refer to Table (3.2).

3.3 The Coalition Game of the Blue Whiting Fishery

In this section, we calculate the net present values for the coalition game setting. We do not, however, calculate the net present values for every possible coalition structure of the game but restrict our analysis to calculate the payoffs of the coastal state coalition and the payoffs accruing to its members from unilateral free-rider behaviour. In addition, we calculate the individual payoff to players when all act noncooperatively.

For the single-player coalitions (singletons), we assume that the countries play a noncooperative game. This means that when a country does not belong to any coalition, it does not cooperate, and all it can do is maximize its own profit, taking into account the strategies of the other players.

For a coalition consisting of three or four countries, the countries outside the coalition will play noncooperatively against the coalition members. Thus, the members of the coalition will try to do their best, taking into account the actions of the outside countries and vice versa.

Under full cooperation, the value of the grand coalition where all players are cooperating, is given by maximizing the sum of net revenues of the countries.

To simulate the possible outcomes of this fishery under the climatic scenarios outlined above, an age structured bioeconomic model was used[9]. Assume that all the countries participating in the blue whiting fishery are represented in the game as the EU (European Union), FO (Faroe Islands), IS (Iceland), NO (Norway), and RU (Russian Federation). Also consider the management of this fishery to be the constant effort strategy[10] that maximizes the net present value of profits (NPV) over a 35-year period.

Let us continue with the coalition analysis of the climate change scenarios outlined above. First, an increase in inflow of Atlantic water, cf. Scenario 1 Table (3.1), in contrast to Ekerhovd (2008) and the second scenario, cf. Table (3.2), expands the distribution of the blue whiting eastward into the Barents Sea such that Russia will become a coastal state, and the grand coalition (sole-owner) and the coastal state coalition is identical. The resulting payoffs to the various coalition structures are shown in Table (3.3). The first result is the payoff to a coalition consisting of all the coastal states. Next, Table (3.3) presents the payoff to the individual nations from unilaterally leaving the grand coalition, starting with Russia, if they act as singletons (free-riding) while the other nations remain in a coalition. The latter's payoffs are listed under CS in the tables. We see that, although the grand coalition's payoff of NOK 7,871 million (m) is large enough to compensate one member its free-riding payoff while the rest remain in the coalition, and leave the remaining countries as least as well off (subtract the payoffs under CS in Table (3.3) from 7,871 m, and compare the results with each coastal state's free-rider payoffs), the sum of all the free-riding payoffs exceeds the payoff of the grand coalition;

---

[9] This model is presented in Ekerhovd (2008)

[10] A constant effort strategy (although it may seem very simplistic) corresponds to a variable catch strategy, which 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 costs or difficulties in transferring fishing effort between different fisheries (Pintassilgo, 2003).

NOK 12,937 m, 19,328 m, and 16,214 m for the scenarios 1a, 1b, and 1c, respectively, compared to NOK 7,871 m. Therefore, in a strict sense, the grand coalition cannot be said to be a stable coalition structure.

Let us now consider the stability of the coastal state coalition if unilateral deviations is not an option, but any deviation from the coastal state agreement breaks down any coalition and all the players revert to noncooperative behaviour. As is shown in Table (3.3), there is no unique solution when all act as singletons. There are multiple strategy combinations that can be considered best response for all players. Table (3.3) presents average payoffs to each player along with maximum and minimum payoffs. The maximum solutions are probably not feasible for all players simultaneously and the minimum is zero for all players. However, if the average (mean) payoffs can be taken as an example of what the players can expect to gain by acting noncooperatively, the sum of all the singleton payoffs is less than the payoff to the grand coalition. The sum of the payoffs of the coastal states when they all act noncooperatively, NOK 4,367 m, 5,205 m, and 4,922 m for the scenarios 1a, 1b, and 1c, respectively, are less than NOK 7,871 m; the payoff of the grand coalition. Thus, the coastal state agreement can be considered stable and the Nash equilibrium of the coalition game.

Table (3.4) shows the coalition payoffs of the second climate change scenario, *i.e*, the stock is distributed according to the shares shown in Table (3.2), where the inflow of Atlantic water to the Norwegian Sea is reduced, resulting in a more western distribution of the blue whiting stock. The spawning takes place in the EEZs of the EU, the Faroe Island and Iceland; in Scenario 2c in Norway's EEZ as well, and there is no blue whiting in Russia's EEZ. Hence, Russia is not a partner in the blue whiting agreement and therefore always operates as a free rider. We see that the benefits provided in terms of payoff when all the coastal states cooperate in a coalition, NOK 3,635 m and 3,699 m with respect to Scenario 2a, and Scenario 2b and 2c, are insufficient to compensate the free-riders with their payoffs acting as singletons while the others continue as a smaller coalition. Nor is the payoff earned by the coastal state coalition larger than the sum of the payoffs when

Table 3.3: Scenario 1: Blue Whiting Game - Payoffs

Scenario 1a								
			Payoffs - Net Present Value†					
Coalition Structure		Total	CS	EU	FO	IS	NO	RU
Sole-Owner		7871						
(EU,FO,IS,NO),(RU)		7074	3852					3222
(EU,FO,IS,RU),(NO)		7170	3708				3462	
(EU,FO,NO,RU),(IS)		7102	3801			3302		
(EU,IS,NO,RU),(FO)		7481	6079		1402			
(FO,IS,NO,RU),(EU)		7417	5868	1549				
(EU),(FO),(IS),(NO),(RU)	MEAN	4367		1024	903	775	882	784
	MAX			2178	2072	1932	2066	1743
	MIN			0	0	0	0	0
Scenario 1b								
			Payoffs - Net Present Value†					
Coalition Structure		Total	CS	EU	FO	IS	NO	RU
Sole-Owner		7871						
(EU,FO,IS,NO),(RU)		7792	1935					5857
(EU,FO,IS,RU),(NO)		6901	3565				3337	
(EU,FO,NO,RU),(IS)		6887	3644			3243		
(EU,IS,NO,RU),(FO)		6934	3507		3427			
(FO,IS,NO,RU),(EU)		6977	3513	3464				
(EU),(FO),(IS),(NO),(RU)	MEAN	5205		1095	1077	1046	1039	947
	MAX			2590	2607	2482	2847	2556
	MIN			0	0	0	0	0
Scenario 1c								
			Payoffs - Net Present Value†					
Coalition Structure		Total	CS	EU	FO	IS	NO	RU
Sole-Owner		7871						
(EU,FO,IS,NO),(RU)		6774	3810					2964
(EU,FO,IS,RU),(NO)		6903	3621				3282	
(EU,FO,NO,RU),(IS)		6903	3621			3282		
(EU,IS,NO,RU),(FO)		6903	3621		3282			
(FO,IS,NO,RU),(EU)		6996	3592	3404				
(EU),(FO),(IS),(NO),(RU)	MEAN	4922		1068	1019	1019	1019	797
	MAX			2431	2335	2335	2335	2056
	MIN			0	0	0	0	0

†Values of NPV in million Norwegian kroner (NOK).

Table 3.4: Scenario 2: Blue Whiting Game - Payoffs

Scenario 2a								
			Payoffs - Net Present Value†					
Coalition Structure		Total	CS	EU	FO	IS	NO	RU
(EU,FO,IS,NO),(RU)		6934	3635					3299
(EU,FO,IS),(NO),(RU)		5640	2267				1712	1662
(EU,FO,NO),(IS),(RU)		5771	2252			1814		1704
(EU,IS,NO),(FO),(RU)		5771	2252		1814			1704
(FO,IS,NO),(EU),(RU)		5982	2017	2283				1682
(EU),(FO),(IS),(NO),(RU)	MEAN	4886	4055*	1228	961	961	905	831
	MAX			2546	2223	2223	1971	1820
	MIN			0	0	0	0	0
Scenario 2b								
			Payoffs - Net Present Value†					
Coalition Structure		Total	CS	EU	FO	IS	NO	RU
(EU,FO,IS,NO),(RU)		6972	3699					3273
(EU,FO,IS),(NO),(RU)		6392	2947				2582	864
(EU,FO,NO),(IS),(RU)		6535	3115			2744		676
(EU,IS,NO),(FO),(RU)		6535	3115		2744			676
(FO,IS,NO),(EU),(RU)		6684	2808	3198				678
(EU),(FO),(IS),(NO),(RU)	MEAN	5124	4121*	1193	1003	1003	922	1003
	MAX			2955	2509	2509	2233	2298
	MIN			0	0	0	0	0
Scenario 2c								
			Payoffs - Net Present Value†					
Coalition Structure		Total	CS	EU	FO	IS	NO	RU
(EU,FO,IS,NO),(RU)		6972	3699					3273
(EU,FO,IS),(NO),(RU)		5806	2017				2265	1524
(EU,FO,NO),(IS),(RU)		5806	2017			2265		1524
(EU,IS,NO),(FO),(RU)		5806	2017		2265			1524
(FO,IS,NO),(EU),(RU)		6420	2715	2841				865
(EU),(FO),(IS),(NO),(RU)	MEAN	5128	4120*	1056	1021	1021	1021	1008
	MAX			2494	2435	2435	2435	2357
	MIN			0	0	0	0	0

†Values of NPV in million Norwegian kroner (NOK).

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

all players act noncooperatively. The sums of the payoffs of the coastal states when all players act noncooperatively, NOK 4,055 m, 4,121 m, and 4,120 m for the scenarios 2a, 2b, and 2c, respectively, are higher than NOK 3,635 m and 3,699 m; the payoffs to the coastal state coalition for the scenarios 2a, and 2b and 2c, respectively. Thus, in the scenario where global warming leads to a colder climate in Northern Europe and the blue whiting has a more western distribution than at present, a coastal state coalition cannot be stable under any circumstances, not even if the threat points are the noncooperative payoffs.

It is important to note that in the presence of non-unique equilibrium this result was based on the average of all the different possible solutions. If we had chosen one of the possible solutions, the cooperative solution could possibly be a better solution than the sum of the singletons payoffs of the coastal states. However, due to the lack of a better equilibrium selection criteria, in the presence of multiple equilibria we decided use the average of the equilibria payoffs as a representation of the payoffs the players could expect in the coalition structure where non-uniqueness occur.

In Scenario 1, with a high NAO index, increased ocean temperatures and salinity in the Norwegian Sea and the Barents Sea, we assumed that the blue whiting migrated into Russian waters and that Russia achieved the status of being a coastal state with regard to the management of this stock. The change in status from being regarded as a distant water fishing nation by the original coastal states to be accepted and included as a coastal state in the management of a straddling fish stock when the stock for some reason changes its migration pattern and distribution is not necessarily a straight forward process. It might take years before the new status is generally accepted by the others, as the shift in the distribution can be a gradual process with a considerable amount of short term variation, meaning that there may be considerable doubt as to whether a shift in distribution is only a temporary change or if the fish stock actually has changed its migration pattern and area of distribution permanently. During the period of transition, the underlying uncertainty might put an established agreement on the management of the stock among the original coastal states at risk, as the emerging coastal state tries to prove its claim to the stock by severely increasing its fishing effort and thus its catches in order to establish rights to the fishery and gain acceptance for their new status. The original coastal states' members might try to limit the prospective coastal state's profit by increasing their fishing efforts too. If this transient period lasts for a long time and the noncooperative behaviour is allowed to continue, it might threaten the fishery, as the stock cannot sustain a too high fishing mortality indefinitely without either becoming extinct or being driven to the break-even stock level (the level at which further fishing becomes unprofitable).

However, when an agreement that includes all countries is finally reached, as in the case of Scenario 1, the coastal state coalition will act as a sole owner, not as in Scenario 2 where Russia always acts as a singleton player while the coastal state coalition maximizes its own profit, taking the action of Russia as given. The sole owner payoff being the maximum attainable profit, the agents in such a management agreement will never find themselves in a situation like Scenario 2, where the sum of the payoffs in a coalition structure where some or all players act as singletons exceeds the payoff to the coastal state coalition. In the case of a low NAO index and less inflow of Atlantic water, Russia is no longer regarded a coastal state; the coalition of coastal states is no longer stable even if the coalition formation options were restricted to full cooperation among the coastal states, where the alternative would be to revert to a state where all acts as singletons. In the opposite case of high NAO index and increased inflow of Atlantic water, the coastal state coalition would be stable if such a restriction were put on the coalition structure. However, if this is not the case, the individual members of the coastal state coalition would have incentives to free-ride on the agreement if the remaining coalition continued to cooperate. What has become evident from our exercise is that if the Northeast Atlantic should cool down in spite of global warming so that the distribution area of the blue whiting stock would be reduced, the cooperation among the coastal states would become even more difficult than it is already and the blue whiting stock would almost certainly collapse.

3.4 Summary and Conclusions

This paper analysed how different climate change scenarios might affect the formation, stability and success of the coastal state coalition on the management of the Northeast Atlantic blue whiting fish stock. We assume that the blue whiting will change its migration pattern and distribution area in response to changes in ocean temperature and salinity. Two possible climate change scenarios were analyzed. First, an increased inflow of relatively warm and saline Atlantic water into the Norwegian Sea and the Barents Sea shifts the distribution of the blue whiting in a northeasterly direction with spawning activity in Norwegian waters and blue whiting catches in Russian waters, making Russia a member of the coastal state coalition. In the second scenario, less Atlantic water flows into the Norwegian Sea and the Barents Sea, reducing the ocean temperatures and salinities along the Norwegian coast as well as in the Barents Sea. In response to this, the blue whiting would shift its distribution and spawning areas in a more south-western direction, abandoning Russian waters altogether.

These two climate change scenarios are linked to the Northeast Atlantic Oscillation (NAO) index. A high NAO index is associated with strong winds blowing in a northeasterly direction across the Atlantic Ocean pushing warm and saline water into the Norwegian Sea and further northeast into the Barents Sea. A weaker NAO index, on the other hand, means that the winds follow an east-west path across the Atlantic, and that less of the warm and saline Atlantic water enters the Norwegian Sea and the Barents Sea. Based on these scenarios, we formulated three possible combinations of quarterly shares. Each share represents the fraction of the stock available for harvest in a certain area, *i.e.*, the different exclusive economic zones or international waters, at certain times. These shares, along with the model of Ekerhovd (2008), were used to calculate the payoffs to coalitions under different coalition structures.

Finally, this allowed us to analyse the coalition formation, success and stability, in particular coalitions among the coastal states. The coalition analysis indicates that the stability of the blue whiting agreement between the coastal states would remain unchanged relative to today's agreement, cf. Ekerhovd (2008), if global warming means an increase in sea temperatures in the Norwegian Sea and the Barents Sea. However, if the opposite should happen, *i.e.*, the inflow of Atlantic water into these waters is reduced, and thus the distribution areas of the blue whiting stock is also reduced rather than increased as a consequence of global warming, this would weaken the stability of the current coastal state agreement on the management of the blue whiting stock.

Drastic changes in a fish stock's migration pattern might bring the underlying weaknesses of a management regime into the open and the nations that harvest this stock into conflict with each other (Hannesson, 2007). For instance, the coastal state agreement on the management of the Norwegian Spring-spawning herring was suspended for two years, 2003 and 2004 (Hannesson, 2006), when the stock failed to resume its expected migration pattern, by spending the winter in Norwegian coastal waters rather than out in the open Norwegian Sea. The Norwegian fishermen, in particular, were not content with their share of the catches as the stock spent most of its time within the Norwegian EEZ. Another current potential conflict over a fish stock that has changed/expanded its area of distribution is about the Northeast Atlantic mackerel, which has expanded its migrations northwards, probably due to favourable climatic conditions, and is now found and fished in new areas in the international waters of the Norwegian Sea and within the EEZ of Iceland. Iceland, not being a member of the mackerel management agreement, has landed significant amounts of mackerel during summer and autumn in 2007 and 2008. This, in addition to the amounts landed by the member countries, has lead to a total harvest in excess of ICES's recommendations.

In the first climate change scenario, when the Norwegian Sea and the Barents Sea were expected to warm up and the distribution of the blue whiting stock expected to expand northeastward into the EEZ of Russia, the coastal state coalition would be stable if the option of the member states to free-ride on the agreement for some reason did not exist. Then the payoff of the coastal state coalition would always exceed the sum of payoffs to the coastal states acting as singletons, and the coastal states would be better off cooperating in a coalition. However, when the coastal state coalition does not include all the countries that participate in the fishery, as is the case in the second scenario, and in Ekerhovd (2008), Russia is excluded from participating in the coastal state coalition, the coalition payoff is less than a potential grand coalition payoff would be, and a mechanism that prohibits free-riding among the coastal states is not necessarily sufficient to make the coastal state coalition stable. An example where this turns out to be true is Scenario 2 of this paper. What might help remedy this weakness is for the coastal states to transfer some of their sovereignty over the fish stock staying in their national EEZs to a regional fisheries management organization (RFMO) and let it manage the fish stock. According to the law of the sea, membership in a RFMO is open to all countries with real interest in the fish stock (Bjørndal and Munro, 2003). The open membership of the RFMOs guarantees a share of the profits to all interested parties as well as being able to provide a higher payoff than any partial cooperation. Furthermore, if it is able to enforce mechanisms that will deter its members from free riding, the prospects for cooperation will be improved.

However, it is possible that this is partially achieved in the management of the blue whiting stock. The coastal states agree on a total allowable catch (TAC) for the stock. This TAC is then divided among coastal states, and in addition a share thereof is set aside to be harvested in international waters. The local RFMO, the North East Atlantic Fisheries Commission (NEAFC), is given the responsibility of dividing this share among all the interested parties, including Russia. Moreover, Russia could be further accommodated by exchange of quota in their waters against being allowed to fish some of the coastal states' shares in their respective EEZs. This can be seen as a way of sharing the benefits of cooperation through side-payments and, by providing higher benefit than a simple coastal state regime would be able to, a more stable management is achieved.

References

ANON. (2004): *Impacts of a Warming Arctic - Artic Climate Impact Assessment.* Cambridge University Press, Cambridge, UK, http://www.acia.uaf.edu.

——— (2008): "Klimaendringer i Barentshavet (Climate Change in the Barents Sea) - Konsekvenser av økte CO_2-nivåer i atmosfæren og havet," ed. by H. Loeng. Rapportserie Nr. 126. Norsk Polarinstitutt (Norwegian Polar Institute), Tromsø, Norway.

BAILEY, R. S. (1982): "The Population Biology of Blue Whiting in the North Atlantic," *Advances in Marine Biology*, 19, 257–355.

BJØRNDAL, T. (2008): "Overview, Roles, and Performance of the North East Atlantic Fisheries Commission (NEAFC)," SNF working paper series. Institute for Research in Economics and Business Adminstration (SNF), Bergen, Norway.

BJØRNDAL, T., AND G. R. MUNRO (2003): "The Management of High Seas Fisheries Resources and the Implementation of the UN Fish Stocks Agreement of 1995," in *The International Yearbook of Environmental and Resource Economics 2003-2004*, ed. by H. Folmer, and T. Tietenberg, New Horizons in Environmental Economics, chap. 1, pp. 1–35. Edward Elgar, Cheltenham, UK.

BLINDHEIM, J. (2004): "Oceanography and climate," in *The Norwegian Sea Ecosystem*, ed. by H. R. Skjoldal, chap. 4, pp. 65–96. Tapir Academic Press, Trondheim, Norway.

EKERHOVD, N.-A. (2008): "The Blue Whiting Coalition Game," SNF Working Paper 23/08. Institute for Research in Economics and Business Administration (SNF), Bergen, Norway.

HANNESSON, R. (2006): "Sharing the herring: fish migrations, strategic advantage and climate change," in *Climate Change and the Economics of the World's Fisheries: Examples of Small Pelagic Stocks*, ed. by R. Hannesson, M. Barange, and S. F.

Herrick, New Horizons in Environmental Economics, chap. 3, pp. 66–99. Edward Elgar, Cheltenham, UK; Northampton, MA, USA.

——— (2007): "Global Warming and Fish Migrations," *Natural Resource Modeling*, 20(2), 301–319.

Hátún, H., J. A. Jacobsen, and A. B. Sandø (2007): "Environmental influence on the spawning distribution and migration of northern blue whiting (*Micromesistius poutassou*)," Discussion Paper ICES CM/B:06, International Council for the Exploration of the Seas Northern Pelagic Working Group.

Hátún, H., A. B. Sandø, H. Drange, B. Hansen, and H. Valdimarsson (2005): "Influence of the Atlantic Subpolar Gyre on the Termohaline Circulation," *Science*, 309, 1841–1844.

ICES (2007): "Report of the Northern Pelagic and Blue Whiting Working Group, 2007," International Council for the Exploration of the Seas (ICES), Advisory Committee on Fishery Management, CM 2007/ACFM:29, Copenhagen.

Pintassilgo, P. (2003): "A Coalition Approach to the Management of High Seas Fisheries in the Presence of Externalities," *Natural Resource Modeling*, 16(2), 175–197.

Skjoldal, H. R., and R. Sætre (2004): "Climate and ecosystem variability," in *The Norwegian Sea Ecosystem*, ed. by H. R. Skjoldal, chap. 18, pp. 507–534. Tapir Academic Press, Trondheim, Norway.

Stenevik, E. K., and S. Sundby (2007): "Impacts of climate change on commercial fish stocks in Norwegian waters," *Marine Policy*, 31, 19–31.

Chapter 4

Individual Vessel Quotas and Unregulated Species: The Norwegian Blue Whiting Fishery

Abstract

This survey of the Norwegian purse seine fleet licensed to fish blue whiting focuses on the relationship between restricted fisheries, such as spring-spawning herring, North Sea herring, mackerel, and capelin, and unrestricted fisheries, of which blue whiting is the most important. To model the behaviour of the fishermen a restricted profit function is used, where species quotas are treated as fixed factors while blue whiting along with other non-quota species are variable factors. We find no relationship between blue whiting and herring, and mackerel. Blue whiting and capelin are substitutes. So are other non-quota species and spring-spawning herring. Other non-quota species are complements to mackerel and North Sea herring.

Keywords: Individual vessel quotas, unregulated fisheries blue whiting trawling, pelagic purse seining, constrained profit function.

JEL Classification: D21, D24, Q22, Q28.

4.1 Introduction

Most fishing vessels target several stocks and species. In biological fisheries management, however, multi-species characteristics are largely ignored, managing the different stocks and species separately. Moreover, only the most important stocks are regulated by individual vessel quotas (IVQs), and for the other stocks there is either a total quota, which allows the fishermen to catch as much as they can until the quota is fished, or there is no quota restriction at all.

When some fisheries are strictly regulated, and some are not, the unregulated ones will attract more of the fishing effort than if none of the fisheries were quota regulated. The reasons for this are the fishermen's incentive to obtain as high a share as possible of the total quota before it is considered fished and the fishery is closed, and the opportunity to increase their income beyond what they are able to earn catching their IVQs. The size of this extra income depends on the characteristics of the unregulated fishery and, more importantly for this work, on the opportunity cost of foregoing a unit of quota fish for one unit of unregulated fish. If the vessels have limited fishing capacity, *i.e.*, the catching of unregulated fish is restricted by the quota fisheries, the unregulated fishery is restricted indirectly by the quotas on other species.

An important unregulated fishery in the North East Atlantic is the blue whiting fishery. Fishing for blue whiting appears to be a very attractive strategy for economic expansion for actors who otherwise operate within a system that is both closed and has strict quota regulations (Standal, 2006). Because blue whiting is a straddling stock, migrating through the exclusive economic zones (EEZs) of several nations as well as on the high seas, there existed no international agreement on the joint management of the stock. Only recently (in 2005) have the largest exploiting nations reached an agreement on a total allowable catch (TAC) for the blue whiting stock. Prior to this agreement the nations competed in catching blue whiting in an effort to establish rights in the fishery and the best possible bargaining position for a future TAC (Ekerhovd, 2003).

Asche *et al.* (2007), in an empirical analysis of Norwegian purse seiners, investigated to what extent fishermen target unregulated species when IVQs are used to manage the regulated species. Their results indicate that restricted and unrestricted outputs are substitutes, and accordingly a reduction in the quotas induces firms to increase production of unregulated species. Moreover, Asche *et al.* found the supply elasticity for the unregulated species to be close to zero and statistically insignificant. Hence, it is not the price of the unregulated species that determines catches and fishing effort for these species. This supports the notion that IVQs give strong incentives to increase fishing effort for unregulated species, particularly when the quotas are reduced.

What separates this work from that of Asche *et al.* (2007) is that while they analyse the behaviour of purse seiners without a blue whiting fishing licence, here we analyse a subfleet of the purse seiners licensed to fish blue whiting in addition to the species targeted by all Norwegian purse seiners. Instead of combining all unregulated outputs into one index for variable output, we specify two unregulated outputs: blue whiting and other non-quota species. This allows us to analyse the effects of the quota on restricted fisheries on the landings of blue whiting. Furthermore, we can compare the quota species' effects on other non-quota species with the results of Asche *et al.*.

Each year the purse seine vessels are given IVQs for the stocks of spring-spawning herring, North Sea herring, mackerel, and capelin. The quotas have to be fished within that year, otherwise they are lost to the vessels. Transferring quotas, or some of them, given in any one year to the next year is not allowed. The purse seiners have the opportunity to fish some non-quota species in addition to the quotas. The blue whiting fishery is one non-quota option for those purse seine vessels holding a blue whiting fishing licence. The quota species and non-quota species are targeted species-by-species, and stock-by-stock, so by-catch is not an issue in these fisheries.

The fact that the species/stocks are targeted one at a time suggests that the fisheries are not joint in production by technical interdependence. However, there is another potential source of jointness in production: allocatable fixed factors Shumway *et al.*

(1984), when “there is a fixed input which is not fully utilized in producing a single product at optimal scale”, Leathers (1991) (p. 1086).

The Norwegian purse seine vessels face several fixed factors in production: in the short run, the IVQs allocated to each vessel each year and, in the long run, the vessel size, in particular their capacity to catch fish. Then there is the choice of how much time to spend fishing for the non-quota species, assuming that IVQs are binding, *i.e.*, that the allocated individual vessel quotas will be fished by the end of the year. If all the fixed factors, IVQs, fishing capacity, and time, are binding, the production of the quota-restricted species and the non-quota species will be joint. Consequently, there will be a substitute relationship between the non-quota species landings and the quotas of spring-spawning herring, mackerel and North Sea herring, and capelin. A substitute relationship means that an increase in the quota of one species, holding the quotas of the other species fixed, will decrease the landings of the non-quota species. However, if one or more of the fixed factors are not binding, either the relationships are statistically insignificant or the non-quota species and the quota species are complements. This means that an increased quota will lead to an increase in landings of non-quota species as well.

While the results indicate that blue whiting and capelin are substitutes, the elasticity of intensity associated with blue whiting is close to zero and statistically insignificant with respect to spring-spawning herring, and mackerel and North Sea herring, the most important quota-regulated fisheries. Moreover, the supply elasticity for blue whiting is positive with respect to other non-quota species and negative with respect to fuel, and statistically significant, while the own-price elasticity is close to zero and statistically insignificant. Hence, it is neither the price of blue whiting nor the quotas on herring and mackerel that determines the landings and fishing effort for blue whiting, but rather the capelin quotas, the price for other non-quota species, and the operation costs, *i.e.*, the price of fuel.

For other non-quota species we see that the landings and fishing effort directed towards these fisheries is to some degree dependent on their own price and the price of fuel, but not on the price of blue whiting. Other non-quota species appear to have a substitute relationship with spring-spawning herring but are complementary to mackerel and North Sea herring.

This chapter is organized in the following way. The theory is reviewed in Section 4.2. Section 4.3 describes the industry and the data used in the estimation. Section 4.4 presents the empirical model and Section 4.5 the estimation strategies. Section 4.6 reports the results and Section 4.7 concludes.

4.2 Theory

Profit maximization can be a good approximation of the behaviour of the skippers/vessel owners in the relatively unrestricted blue whiting fishery that is free of individual vessel quotas (Squires, 1987, 1988; Squires and Kirkley, 1991) as opposed to the strictly regulated purse seine fisheries for spring-spawning herring, mackerel and North Sea herring, and capelin, where cost minimization is often considered the proper representation of fishermen's behaviour (Weninger, 1998; Bjørndal and Gordon, 2000; Nøstbakken, 2006).

Both Moschini (1988) and Fulginiti and Perrin (1993) provide a framework for supply management in agriculture. This framework is easily extended to a fishery were some, but not all, outputs are quota regulated.

Consider a production process where a vector y of I outputs is produced during a given period using a vector x of J variable inputs and a vector z of K fixed inputs.

If the maximum allowable output for some components of the vector y is constrained, as in fisheries with individual vessel quotas, total variable profit is maximized when the profit from the unconstrained outputs is maximized. Thus, if the output vector y is partitioned into a subvector y^0 of I^0 for which the constraint is binding and a subvector y^1 of I^1 unconstrained products, and if the output price vector is similarly partitioned into p^0 and p^1, the restricted profit function is defined as:

$$\pi^R(p^1, w, y^0, z) = \max_{y^1}\{p^{1\prime}y^1 - C(y^1, y^0, w, z)\}. \tag{4.1}$$

Given the properties of the cost function, the restricted profit function $\pi^R(p^1, w, y^0, z)$ is non-decreasing in p^1 and z, non-increasing in w and y^0, convex in (p^1, w), and continuous and twice differentiable. Here, $\pi^R(p^1, w, y^0, z)$ can be viewed as a form of McFadden's (1978) restricted profit function and of Diewert's (1982) variable profit function, with the explicit extension of the constraints to the output side, which implies that the restricted profit function $\pi^R(p^1, w, y^0, z)$ does not satisfy the property of non-negativity (Moschini, 1988).

The restricted profit function satisfies the derivative property (Hotelling's lemma):

$$y^1(p^1, w, y^0, z) = \nabla_{p^1}\pi^R(p^1, w, y^0, z), \tag{4.2}$$

$$x(p^1, w, y^0, z) = -\nabla_w\pi^R(p^1, w, y^0, z), \tag{4.3}$$

where ∇ indicates a vector of partial derivatives, and $y^1(p^1, w, y^0, z)$ and $x(p^1, w, y^0, z)$ are the vectors of the unrestricted output supply and variable input demand that maximize profits. From a restricted profit function $\pi^R(p^1, w, y^0, z)$, Hotelling's lemma allows the derivation of an estimable system of output supplies and input demands consistent with the constraint of the underlying technology and with profit maximization under supply constraints. This makes it explicit that the supply of products not subject to supply management and the demand of variable inputs in general depend on the level of restricted commodities, and this dependency can be quantified and tested in empirical applications.

The shadow value of quota holdings is measured as the value to the vessel of a unit increase in quota holdings. The shadow value of the n^{th} vessel, for the quota species, y^0, is written as:

$$SV_n^{y^0} = p_n^0 + \frac{\partial \pi_n^R}{\partial y^0}. \tag{4.4}$$

The term, p_n^0, is the price paid to vessel n per unit of quota landed of output y^0, where $n = 1, ..., N$. The second term on the right-hand side of (4.4) represents the change in restricted profit of non-quota landings associated with a one unit change in the quota species in question.

A change in quota landings results in two separate effects on restricted profit: *i*) A one-unit increase in quota landings will increase marginal costs through an increase in the variable input factor necessary to land the additional quota. This will have an unambiguously negative effect on restricted profit that is not related to quota. *ii*) The change in restricted profit from non-quota landings depends on whether there is a substitute or a complementary relationship between non-quota and quota landings. If non-quota and quota landings are substitutes, then marginal restricted profit from non-quota landings will decline as quota landings increase. A complementary relationship will increase marginal restricted profit as landings of quota species increase. The change in restricted profit from non-quota landings for each individual vessel is conditioned on vessel characteristics and other quota holdings.

Following Dupont and Gordon (2007), the two separate effects on marginal restricted profit are separated out by calculating the marginal shadow value (MSV), which focuses only on the decline in restricted profits resulting from the increase in the marginal cost of landing an additional unit of quota.

$$MSV_n^{y^0} = SV_n^{y^0} - \sum_{I^1} \frac{\partial y^1}{\partial y^0} p^1. \tag{4.5}$$

The elasticity of intensity of unrestricted non-quota outputs with respect to quota output and the shadow value of each of the output- regulated species are two fundamental characteristics of the production structure. The elasticity of intensity is a measure of the change in non-quota landings caused by a one-percentage change in quota landings for a specific species (Diewert, 1974). The elasticity of intensity of non-quota landings associated with quota-restricted factors is defined as:

$$\eta_{y^1,y^0} = \frac{\partial y^1}{\partial y^0}\frac{y^0}{y^1}. \tag{4.6}$$

A negative elasticity of intensity implies that an increase of one per cent in a quota causes a decline in the harvest of the unrestricted landings indicating a substitute relationship between the output- regulated species and unrestricted landings, whereas a positive elasticity of intensity implies that an increase of one per cent in a quota causes an increase in the harvest of non-quota species. In addition, standard price elasticities can be calculated and are conditional on fixed output and fixed input factors.

4.3 The Industry and Data

The blue whiting (*Micromesistius poutassou*), a small gadoid, characterized as an oceanic semi-pelagic species living in the North East Atlantic (see figure (4.1)), is one of the most abundant fish species in the Norwegian Sea. The blue whiting stock is a straddling stock. Straddling stocks migrate through waters under different jurisdictions, both national exclusive economic zones (EEZs) and international waters. This behaviour complicates the management of these stocks compared to stocks attached only to one or two EEZs. The international management of blue whiting has many similarities with the management of the spring-spawning herring (Bjørndal *et al.*, 2004).

During the period 1970–1997 the blue whiting fishery was dominated by Russia (former Soviet Union) and Norway, which developed it. Since the late 1990s there has been an increased interest in the blue whiting fishery, and the total landings increased from about 650 thousand tonnes in 1997 to 2.3 million tonnes in 2003 (ICES, 2004). Iceland, which previously had for a large part ignored the blue whiting fishery, began to substantially increase its blue whiting landings in 1998 (Ekerhovd, 2003).

Since 1999, there have been several attempts among the coastal states of the

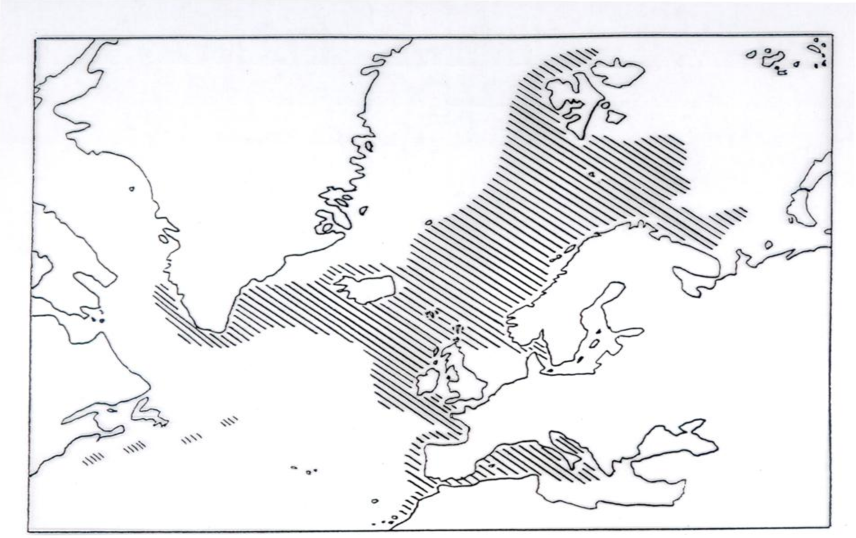

Figure 4.1: The blue whiting distribution in the North East Atlantic

European Union (EU), Norway, Iceland, and Denmark (on behalf of the Faroe Islands and Greenland), and Russia to reach an agreement and set a common maximum total allowable catch (TAC). The negotiations have failed because each nation wants a higher share of the quota than the others are willing to accept (Standal, 2006).

The dispute has led the nations to increase their quotas unilaterally during the fishing season in an effort to keep their catches at a certain level according to their claims and, also, in response to increased quotas of other nations.

However, in December 2005 the coastal states of the EU, the Faroe Islands, Iceland, and Norway signed an agreement. The agreement, starting in 2006, includes a long run management strategy that implies annual reductions in the landings until the management goals are reached[1].

---

[1] Source: Stortingsmelding nr. 22, 2005–2006, “Om dei fiskeriavtalane Noreg har ingått med andre land for 2006 og fisket etter avtalane i 2004 og 2005”, Det Kongelege Fiskeri- og Kystdepartementet (The Norwegian Ministry of Fisheries and Coastal Affairs).

4.3.1 The Norwegian Fishery Management System

According to Årland and Bjørndal (2002), two main characteristics of the Norwegian fisheries management system are restricted access through licensing schemes and restricted harvesting levels through quotas. Capacity is restricted through licensing in the purse seine fleet. To be allowed to fish blue whiting a special licence is needed[2].

Although, in reality, the licences are transferable, this system is rigid compared to individual transferable quotas and does not lead to a reduction in overcapacity. To facilitate this the so- called unit quota system was implemented, which allows for the concentration of more quotas per vessel (Årland and Bjørndal, 2002). However, the unit quota system has not been as effective as some had hoped for. The fact that these quota rights only last for 13 or 18 years has made the purchase of additional quotas through the unit quota system less attractive than it would have been had the property right to the quota been permanent. Transfer of fishing rights has to be approved by the fisheries authorities. Facilitation of approval requires the assistance of lawyers and brokers. Thus, high transaction costs are linked to investment in quotas from other vessels (Standal, 2006).

The purse seiners are allocated individual vessel quotas (IVQs)[3] for all targeted species, except for blue whiting and other non-specified species. The blue whiting quotas, set unilaterally by Norway or acquired through exchanging quotas with other nations, are not divided into IVQs, but the vessels are allowed to catch as much as they can until the total quota is fished (Årland and Bjørndal, 2002). Not dividing the total quota into IVQs gives incentives to compete for the fish as the fishery may be closed once the quota has been fished.

---

[2] A licence is issued to a particular owner and a particular vessel. If the vessel is sold or replaced by a new one, a transfer of the fishing licence must be approved by the fishing authorities. Hence, implicit in the price paid for a purse seiner, with the licence transferred to the new owner, is the value of the purse seining licence in general and the blue whiting licence in particular.

[3] The IVQs are "non-transferable" in the sense that they cannot be rented out on a yearly basis, but can be bought and sold as described above.

4.3.2 The Norwegian Blue Whiting Fishing Fleet

The sample used in the estimation consists of an unbalanced panel data series of the combined Norwegian purse seining and pelagic trawler fleets from 1990 to 2003 collected by the Norwegian Directory for Fisheries (1991–2004). The data include vessel length, fuel expenditure, and information on the quantity and value of the landings of fish. The landings are divided into spring-spawning herring, North Sea herring, mackerel, blue whiting, capelin and other unspecified fish species[4]. These vessels target pelagic species, with herring and mackerel as the most important ones, using a purse seine net to catch schools of fish and a pelagic trawl to catch blue whiting[5]. Table (4.1) shows the species targeted by the purse seiners/pelagic trawlers by area, gear type, and the time of the year they fished the respective species[6]; each fishing season has at least one time-overlap with other fishing seasons.

The main fishing of the blue whiting stock takes place from January through April in the North East Atlantic, in waters west of Ireland. This coincides with the capelin fishery of the coast off Finnmark (adjacent to the Barents Sea), and the spring-spawning herring fishery. The spring-spawning herring fishing season lasts from October to April the following year. This means that herring forgone in the winter season, if the vessels choose to fish blue whiting instead, can be caught later. Blue whiting is to some extent fished in summer and early autumn in the Norwegian Sea, but as table (4.1) shows this is probably the busiest time of the year for these vessels, with North Sea herring, mackerel, and capelin to catch in addition to blue whiting[7]. This illustrates that the vessels are more or less fully occupied throughout the year, catching both quota-regulated fish, *i.e.*,

---

[4] Atlantic horse mackerel (*Trachurus trachurus*) and sprat (*Sprattus sprattus*) make up the largest components of the non-quota species and are harvested in the North Sea and adjacent waters.

[5] After locating a school of fish, the vessel sails around it and encircles the fish with a net. By closing the bottom of the seine, a purse is formed. When the seine is pulled, the top of the purse is drawn closed and the fish are trapped in the net purse. Blue whiting, on the other hand, are caught using a pelagic trawl. A trawl is a cone-shaped net pulled through deep water, scooping the fish into the trawl.

[6] "Kart over norske fangster 2001 og 2004". Fiskeridirektoratet (Directorate of fisheries), Bergen, www.fiskeridir.no

[7] Note that individual vessel quotas are given on a yearly basis, from January 1st to December 31st, during which the quotas have to be taken or forfeited

Table 4.1: Fishing seasons for the Norwegian purse seiner fleet, by species, area, gear, and month

		Month	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Species	Area	Gear												
Capelin	Barents Sea	PS	X	X	X	X								
Capelin	Iceland	PS						X	X	X	X			
BW	Norwegian Sea	PT					X	X	X	X	X			
BW	Atlantic	PT	X	X	X	X								
Mackerel	Norway	PS								X	X	X		
Mackerel	North Sea	PS					X	X	X	X	X	X	X	
NSH	North Sea	PS					X	X	X	X	X	X	X	X
SSH	Norway	PS	X	X	X							X	X	X

Source: Fiskeridirektoratet (Directorate of fisheries), Bergen, www.fiskeridir.no

"X" indicates in what months and areas each species is fished.

BW = Blue whiting

NSH = North Sea herring

SSH = Spring-spawning herring

PS = Purse seine

PT = Pelagic trawl

Table 4.2: Summary statistics of the sample vessels

Statistics	Mean	Min	Max	St. Dev.
Variables				
Observations	234	0	0	0
Vessel length (metre)	65.38	49.35	77.4	5.92
Fuel expenditure	3.825	1.039	7.564	1.043
Qty. blue whiting	11,333	61.238	26,670	5,899
Qty. other non-quota	948	0	6,010	1,050
Qty. SSH	3,160	118	7,632	1,579
Qty. North Sea herring	1,069	129	2,804	428
Qty. mackerel	1,522	998	2,648	329
Qty. capelin	3,738	0	12,560	2,294
Value blue whiting	9.648	0.018	32.085	5.653
Value other non-quota	1.828	0	8.157	1.761
Value SSH	9.239	0.445	19.179	4.398
Value North Sea herring	2.754	0.389	6.449	0.977
Value mackerel	10.503	5.454	19.103	2.627
Value capelin	3.788	0	15.093	2.570

Values in million Norwegian Kroner (2001)
Quantities (Qty.) in tonnes
SSH = spring-spawning herring

spring-spawning herring, North Sea herring, mackerel, and capelin, and non-quota fish, such as blue whiting and other non-quota species, and that a change in the quotas can affect the blue whiting quantity and vice versa.

In the analysis we only use data on purse seiners fishing for blue whiting. Table 4.2 reports some summary statistics of the sample of the Norwegian purse seiners/blue whiting trawlers.

Initial econometric work revealed a singularity problem in the regressor matrix. Correlation coefficients, shown in Table (4.3), indicated that the singularity is caused by a high correlation between mackerel and North Sea herring. These species are harvested within the same geographic area under similar environmental conditions and quotas are determined based on similar regulatory principles. It was therefore decided to combine mackerel and North Sea herring into a single restricted output, using a Fisher quantity index for aggregation.

The purse seiners that trawl for blue whiting, in addition to the species caught by purse seine, are a unique fleet segment separable from the other purse seiners. The blue

Table 4.3: Correlation coefficients between harvest quantities

	BW	Other	SSH	NSH	Mackerel	North Sea[†]	Capelin
BW	1.000						
Other	-0.248	1.000					
SSH	0.398	-0.286	1.000				
NSH	-0.120	0.529	-0.419	1.000			
Mackerel	-0.246	0.381	-0.364	0.565	1.000		
North Sea[†]	-0.247	0.483	-0.435	0.768	0.968	1.000	
Capelin	-0.226	-0.047	-0.414	0.058	-0.441	0.366	1.000

[†] North Sea is a Fisher quantity index over the quantities of mackerel and North Sea herring.

whiting is fished with a trawl while the other targeted species are caught using a purse seine. The purse seiners that participate in the blue whiting fishery must be rigged for both trawling and purse seining. Vessels fishing in the North Atlantic during wintertime need to be well built and the size of the pelagic trawl used in the blue whiting fishery requires vessels that are equipped with big engines. The need for power and strength, as well as an ability to handle large catches, separates the blue whiting fleet from the conventional purse seiners. Another feature of the blue whiting fishery distinguishing it from purse seining is the management regime; in most other fisheries targeted by purse seiners the TAC is divided among the individual vessels, while for the blue whiting there were no IVQs prior to 2006. This has lead to an expansion in the blue whiting fishery in order to increase the revenue of the vessels (Standal, 2006).

The purse seiners engaged in blue whiting fishing are usually the larger vessels in the fleet with an average length of about 65 metres and displacement over a thousand tonnes. Because of the size of the pelagic trawls, the vessels require huge engine power in order to be able to operate the gear. Moreover, the fish are stored in the hold in refrigerated seawater. Refrigerating and circulating the seawater, operating the gear, and sailing between the port and fishing grounds burns a large amount of fuel. Fuel expenditure therefore constitutes the vessels main variable cost.

Blue whiting is a very important fishery for these vessels; with respect to quantity, blue

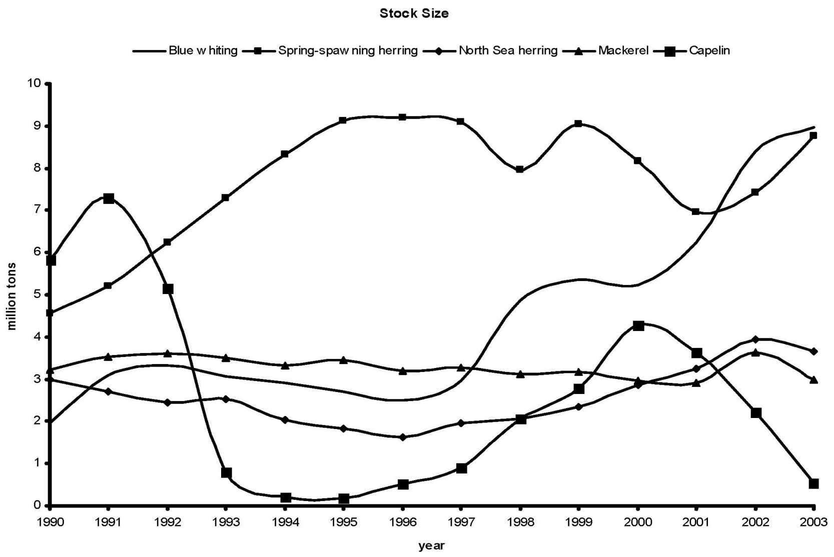

Figure 4.2: Stock size of blue whiting, spring-spawning herring, North Sea herring, mackerel, and Barents Sea capelin

whiting makes up about 52% of the total landings compared to 14.5% for spring-spawning herring and only 7% for mackerel. In value terms[8] blue whiting is still important but to a lesser extent; mackerel is the most valuable fish, making up about 28% of revenue followed by blue whiting (26%) and spring-spawning herring (24%).

Capelin and other non-quota species are not fished by all vessels every year. The capelin fishery in the Barents Sea was banned in the years 1987–1990, 1994–1998, and again from 2004. The fishery was re-opened in the winter season 1991 and again in the winter season 1999, following recovered stocks, see figure (4.2) (ICES, 2004). Then there is the Norwegian quota in the Iceland capelin fishery, which is small compared to the quota in the Barents Sea fishery. In some years vessels skip the Iceland capelin. The other non-quota species are reported unspecified and represent unrestricted landings, *i.e.*, no IVQs are allocated for these species.

---

[8] Monetary values referred to in Table (4.2) are in real 2001 terms.

4.4 Empirical Model

The choice of functional form to be used in estimating a restricted profit function is important because profits can be positive or negative in such a constrained setting. Fulginiti and Perrin (1993) avoid this problem by constraining inputs as well as outputs in order to ensure that variable profits are positive. In this way, they can use a standard translog functional form. However, negative variable profits require alternative functional forms and Moschini (1988) uses a normalized quadratic equation, normalizing using one input factor. Diewert and Wales (1987) and Kohli (1993) show that the estimated results for this functional form depend on the normalization. These authors suggest a symmetric normalized quadratic functional form to avoid this problem and we use this empirical equation here.

A normalized quadratic functional form is well suited to modelling multiple-output technologies and it is easy to impose curvature properties on the model (Diewert and Wales, 1987; Kohli, 1993). Moreover, the restricted profit function, characterized by Lau (1976), can also illustrate the economic value of the restrictions (Moschini, 1988). Obtaining the shadow prices per unit of a non-quota species conditioned on the vessel's own quota holdings allows us to obtain shadow values indirectly through observed choices (Dupont and Gordon, 2007).

We start by defining a normalized quadratic restricted profit function (Lau, 1976; Diewert and Ostensoe, 1988; Moschini, 1988; Dupont and Gordon, 2007) for the Norwegian purse seine vessels licensed to fish blue whiting over the prices of three variable factors: The price of fuel[9] (F), as a variable input factor, and prices of blue whiting (BW) and other unspecified non-quota fish species (O) as variable outputs. The variable quantities are conditioned on four fixed factors: Vessel length, L, as a proxy for capital, and fish landings under supply management: Spring-spawning herring (H), mackerel and

---

[9] The price of fuel is not included in the costs and earnings survey—only fuel expenditure; instead, an index for the wholesale prices for solid, liquid, and gaseous fuels and related products was used as a proxy for the fuel prices. Source: Statistics Norway, www.ssb.no

North Sea herring (M)[10], and capelin (C). The normalized restricted profit function, assuming constant returns to scale[11], can be written in the following way:

$$
\begin{aligned}
\pi^R(p;\bar{q}) \equiv & \frac{1}{2}\left(\alpha'\bar{q}\sum_{i=1}^{3}\sum_{k=1}^{3} a_{i,k}p_i p_k\right)/p_f \\
& + \frac{1}{2}\left(\beta' p\sum_{j=1}^{4}\sum_{h=1}^{4} b_{j,h}\bar{q}_j\bar{q}_h\right)/\bar{q}_L \\
& + \sum_{i=1}^{3}\sum_{j=1}^{4} c_{i,j}p_i\bar{q}_j,
\end{aligned} \tag{4.7}
$$

where the prices of the variable quantities are indexed i and k, while the fixed factor quantities are indexed j and h. The function is normalized and thus p_F and $\bar{q}_L$ are chosen as *numèraires*[12].

We define matrix A with elements $a_{i,k}$. Because of the linear relationship between rows and columns in matrix A caused by linear homogeneity, the first row and column of A, are vectors of zeroes, $a_{F,k}$ through $a_{k,F}$ for the price of blue whiting, other non-quota species and fuel, respectively. Similarly, we define the matrix B with elements $b_{j,h}$. Because of linear homogeneity, the first row and column in matrix B are vectors of zeroes, and $b_{L,h}$ through $b_{h,L}$ are for vessel length and spring-spawning herring, mackerel and North Sea herring, and capelin landings.

Following Dupont and Gordon (2007), $\alpha'\bar{q}$ is defined as a Fisher quantity index over the fixed factors, $\bar{q}_j$, $j = L, H, M, C$[13], and $\beta' p$ is defined as a Fisher price index over the variable input and output prices p_i, $i = O, BW, F$.

The normalized quadratic profit function described in equation (4.7) must satisfy the conditions required for it to represent the underlying production technology. The

---

[10] The quantity, q_M, is a Fisher quantity index over the quantities of mackerel and North Sea herring.

[11] The constant returns to scale assumption rests upon the fact that the vessels in the sample are fairly large and the assumption that an increase in size leads to only a proportional increase in capacity

[12] Given that we want to know something about the relationship between the variable and the fixed outputs, using the variable and fixed inputs as *numèraires* seems to be the natural choice

[13] The effective interest rate, Norwegian InterBank Offered Rate (NIBOR), is used as a proxy for the price of capital. Source: Norges Bank, The Norwegian Central Bank, Oslo.

function is linear homogeneous, convex in prices and concave in fixed factors, separately. Symmetry in the cross-price and cross-quantity terms is obtained by defining the matrices A and B to be symmetric. The restricted profit function is convex in prices and concave in fixed factors globally, as well as locally, whenever the A matrix is positive semi-definite and the B matrix is negative semi-definite (Diewert and Wales, 1987).

Instead of estimating the restricted profit function in (4.7), it is more convenient to estimate the system of the three variable quantity equations given in (4.8), (4.9), and (4.10). These equations, two for the supply of variable landings and one for the demand for fuel, are obtained by using Hotelling's lemma. These equations are formulated in actual quantities, not input or revenue shares; therefore, all three equations must be estimated to obtain the parameters in equation (4.7).

$$\begin{aligned}\frac{\partial \pi^R}{\partial p_O} &= q_O(p_O, p_{BW}, p_F; \bar{q}_L, \bar{q}_H, \bar{q}_M, \bar{q}_C) \\ &= \alpha'\bar{q}\Big(a_{O,O}p_O + a_{O,BW}p_{BW}\Big)/p_F \\ &+ \frac{1}{2}\Big(\beta_O \sum_{j=2}^{4}\sum_{h=2}^{4} b_{j,h}\bar{q}_j\bar{q}_h\Big)/\bar{q}_L \\ &+ \sum_{j=1}^{4} c_{O,j}\bar{q}_j,\end{aligned} \tag{4.8}$$

$$\begin{aligned}\frac{\partial \pi^R}{\partial p_{BW}} &= q_{BW}(p_O, p_{BW}, p_F; \bar{q}_L, \bar{q}_H, \bar{q}_M, \bar{q}_C) \\ &= \alpha'\bar{q}\Big(a_{O,BW}p_O + a_{BW,BW}p_{BW}\Big)/p_F \\ &+ \frac{1}{2}\Big(\beta_{BW} \sum_{j=2}^{4}\sum_{h=2}^{4} b_{j,h}\bar{q}_j\bar{q}_h\Big)/\bar{q}_L \\ &+ \sum_{j=1}^{4} c_{BW,j}\bar{q}_j,\end{aligned} \tag{4.9}$$

$$\begin{aligned}\frac{\partial\pi^R}{\partial p_F} &= -q_F(p_O, p_{BW}, p_F; \bar{q}_L, \bar{q}_H, \bar{q}_M, \bar{q}_C) \\ &= -\frac{1}{2}\left(\alpha'\bar{q}\sum_{i=1}^{2}\sum_{k=1}^{2} a_{i,k}p_ip_k\right)/p_F^2 \\ &+ \frac{1}{2}\left(\beta_f\sum_{j=2}^{4}\sum_{h=2}^{4} b_{j,h}\bar{q}_j\bar{q}_h\right)/\bar{q}_L \\ &+ \sum_{j=1}^{4} c_{F,j}\bar{q}_j,\end{aligned} \tag{4.10}$$

for $i, k = O, BW, F$ and $j, h = L, H, M, C$.

Cross-equation and symmetry restrictions, $a_{i,k} = a_{k,i}$ for i, k and $b_{j,h} = b_{h,j}$ for j, h in both equations, have already been imposed in (4.8), (4.9), and (4.10). The linear homogeneity restrictions, $a_{i,F} = 0$ for $i = O, BW, F$, and $b_{j,L} = 0$ for $j = L, H, M, C$, are imposed by dropping them from the estimating equations. β_i, $i = O, BW, F$, may be chosen arbitrarily[14] (Diewert and Wales, 1987).

4.5 Estimation Strategy

Prior to estimation, additive disturbance terms are appended to each of the three quantity equations (4.8), (4.9), and (4.10). The estimation begins with the linear system of equations (4.8), (4.9), and (4.10). Zellner's iterative technique for seemingly unrelated regressions is used. The sample consists of an unbalanced panel of 53 vessels, covering the years from 1990 to 2003.

If the unobserved variables are correlated with the other explanatory variables, estimation will yield biased results, *i.e.*, the omitted variable problem.

Over the time period 1990–2003 there were significant changes in technology and restructuring of the fleet (Standal, 2006; Årland and Bjørndal, 2002), in the competition

---

[14] Here, the βs are set such that they sum to one. Although several possible combinations of β_i were tested, the combination that appears to be best suited, $\beta_{BW} = 0.5$ and $\beta_O = \beta_F = 0.25$, is used in the estimations.

between the blue whiting fishing nations (Ekerhovd, 2003), and in the size of the fish stocks (ICES, 2004). Taking account of these changes, the model is estimated with a binary variable for each year[15] with 2001 as the base year.

In addition to the prices of the variable inputs and outputs conditioned on the restricted input and output factors, the restricted profit in non-quota fisheries is expected to depend on the biomass of the stocks of non-quota species as well as the skills of the owner/skipper/crew and the physical characteristics of each vessel[16]. Although the blue whiting stock biomass is given in ICES (2004)[17], the lack of knowledge about what species are included in the other non-quota species component makes it difficult to come up with a good measure for stocks. Despite this, the stock effect is one of several effects controlled for by the dummy variables for each year. That leaves us with the unobserved skills of the owner/skipper/crew, a factor that needs special treatment.

The fixed effects method is a way of neutralizing the unobserved effect of skills. This technique is equivalent to assigning dummies for the vessels, an approach used in this paper. Of the 53 vessels in the sample, 52 vessels were assigned dummy variables[18].

If convexity and concavity are rejected by the data[19], which turns out to be the case, they can be imposed by reparameterization of the A and B matrices using the technique described by Wiley *et al.* (1973) (Dupont, 1991). This reparameterization uses the product of a matrix Δ and its transpose to replace the A matrix, i.e., $A = \Delta\Delta'$. The

---

[15] A binary variable takes the value one for a specific year, and zero for all others.

[16] The physical characteristics of the vessel are correlated with vessel length, which is already in the model.

[17] The annual assessment of the stock is uncertain, but its accuracy improves over time (Sandberg, 2006). The inclusion the blue whiting biomass in the supply equation for blue whiting (4.9) resulted in a negative coefficient so the variable was dropped.

[18] Originally, the data were drawn from the Norwegian purse seiner fleet providing data on pure purse seining vessels as well as purse seiners holding blue whiting licences. Because the focus of this study is on blue whiting, all the pure purse seiners were excluded from the sample. Introduction of the fixed effects method led to further exclusions; it was not possible to estimate the model using fixed effect dummies on vessels that appeared in the data for less than three years. The vessel used as the base vessel was the vessel with the highest observed profit, which was in 2001. Therefore, the fixed effect dummies should be interpreted relative to this vessel in 2001.

[19] Failing to obtain convexity or concavity does not necessarily mean that the assumption of profit maximization is violated. Other reasons may exist, such as insufficient price variation in the data, multicollinearity, and aggregation of input or output quantities to obtain indexes (Squires, 1987; Dupont, 1991).

equivalent for the B matrix is $B = -DD'$. The Δ and D matrices are lower triangular matrices with zeros in the first columns.

$$\begin{bmatrix} a_{F,F} & a_{F,O} & a_{F,BW} \\ a_{O,F} & a_{O,O} & a_{O,BW} \\ a_{BW,F} & a_{BW,O} & a_{BW,BW} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ \delta_1 & 0 & 0 \\ \delta_2 & \delta_3 & 0 \end{bmatrix} * \begin{bmatrix} 0 & \delta_1 & \delta_2 \\ 0 & 0 & \delta_3 \\ 0 & 0 & 0 \end{bmatrix} \tag{4.11}$$

$$\begin{aligned} &\begin{bmatrix} b_{L,L} & b_{L,H} & b_{L,M} & b_{L,C} \\ b_{H,L} & b_{H,H} & b_{H,M} & b_{H,C} \\ b_{M,L} & b_{M,H} & b_{M,M} & b_{M,C} \\ b_{C,L} & b_{C,H} & b_{C,M} & b_{C,C} \end{bmatrix} \\ &= - \begin{bmatrix} 0 & 0 & 0 & 0 \\ d_1 & 0 & 0 & 0 \\ d_2 & d_3 & 0 & 0 \\ d_4 & d_5 & d_6 & 0 \end{bmatrix} * \begin{bmatrix} 0 & d_1 & d_2 & d_4 \\ 0 & 0 & d_3 & d_5 \\ 0 & 0 & 0 & d_6 \\ 0 & 0 & 0 & 0 \end{bmatrix} \end{aligned} \tag{4.12}$$

While it is still possible to obtain separate elasticity estimates for each pair of inputs and outputs, the reparameterization requires a non-linear estimation technique. A new set of equations must be estimated using a non-linear maximum likelihood procedure because the $a_{i,k}$, $i, k = O, BW$, and $b_{j,h}$, $j, h = H, M, C$, parameters, respectively, are replaced by the appropriate combinations of the δ and d parameters from the Δ and D matrices, respectively equations (4.11) and (4.12). The correspondences between the $a_{i,k}$ and δ parameters are as follows: $a_{O,O} = \delta_1^2$, $a_{O,BW} = \delta_1 * \delta_2$, and $a_{BW,BW} = \delta_2^2 + \delta_3^2$. Whereas, the correspondences between the $b_{j,h}$ and the d parameters are $b_{H,H} = -d_1^2$, $b_{H,M} = -d_1 * d_2$, $b_{H,C} = -d_1 * d_4$, $b_{M,M} = -(d_2^2 + d_3^2)$, $b_{M,C} = -(d_2 * d_4 + d_3 * d_5)$, and $b_{C,C} = -(d_4^2 + d_5^2 + d_6^2)$.

4.6 Results

Table (4.4) reports the estimated parameters and standard errors for the estimation of equations (4.8), (4.9), and (4.10). The results for the fixed effect and the year dummies are not reported. Tests for correlation of the data from the vessels with the highest number of observations in the sample (eight and nine years) suggests that the problem of serial correlation is not an issue. Furthermore, because the vessels were all fairly large and of a homogeneous type, the possibility of heteroscedasticity in the variance is considered small.

Columns 1 and 2 in Table (4.4) represent the elements of Δ and D matrices, which will be used in the reparameterization of the A and B matrices. The other columns of Table (4.4) illustrate the effect the constrained factors have on the unrestricted factors, parameters $c_{i,j}$ in equation (4.7), where $i = O, BW, F$ and $j = L, H, M, C$. Standard errors are in the parentheses. The number asterisks indicate the coefficients' statistically significance level, e.g. one for 10%, two for 5% and three for 1%. The results should be interpreted as if keeping all other things constant (*ceteris paribus*).

Table (4.5) shows the price elasticities for the variable factors. Estimates use means of the data. Throughout the asymptotic standard errors (in parentheses) are calculated using the formula for the variance of a random variable that is a non-linear function of several random variables (Davidson and MacKinnon, 2004). The landings of blue whiting are insensitive to changes in its own price, while they appear to be sensitive with regard to the price of other non-quota species and the price of fuel[20]. The landings of blue whiting appear to increase with the price of other non-quota species, which is surprising, but, as expected, decreasing as the price of fuel increases.

The landings of other non-quota species are insensitive to changes in the price of blue whiting, but appear to increase with their own price and decrease with the price of fuel. The amount of fuel increases with the price of blue whiting and the price of

---

[20] Nøstbakken (2006), and Bjørndal and Gordon (2000) also reported the input factor demand for the purse seiners to be inelastic.

Table 4.4: The restricted profit function

Variable name	Δ and D matrices	Dependent variable	Blue whiting	Other non-quota species	Fuel
δ_1	-0.2140***	Independent variable			
	(0.0471)	Vessel length	188157***	1106	-16487***
δ_2	0.5039***		(23734)	(4595)	(5283)
	(0.1987)	Herring quantity	0.0871	-0.2378***	0.1065E-3
δ_3	0.2033E-9		(0.1158)	(0.0379)	(0.0022)
	(0.5799)	North Sea quantity	-0.0625	0.1112***	-0.7197E-3
d_1	0.2806E-3*		(0.0412)	(0.0127)	(0.6999E-3)
	(0.1647E-3)	Capelin quantity	-0.3529***	-0.0528*	-0.0021***
d_2	0.8372E-4		(0.0991)	(0.0285)	(0.8958E-3)
	(0.5078E-4)				
d_3	0.1558E-3***				
	(0.6531E-4)				
d_4	-0.2915E-10				
	(0.3471E-3)				
d_5	0.1606E-10				
	(0.1780E-3)				
d_6	0.3820E-14				
	(0.1671E-3)				

N = 234

Log-likelihood function = -9426.873.

Standard errors are in parentheses.

Table 4.5: Price elasticity estimates

Variable prices	Blue whiting	Other Non-Quota Species	Fuel
Variable quantities			
Blue Whiting	0.0068	0.0169***	-0.0139*
	(0.0053)	(0.0029)	(0.0079)
Other Non-Quota Species	0.0146	0.0364**	-0.0707***
	(0.0136)	(0.0160)	(0.0239)
Fuel	0.0350*	0.0372***	-0.0721***
	(0.0198)	(0.0126)	(0.0281)

other non-quota species, and declines as its own price increases. Hence, the combined purse seiners and blue whiting trawlers seem not only responsive to input price changes but also to changes in the price of the unrestricted outputs, especially the price of other non-quota species. Thus, it is not only available excess capacity and fishing season considerations that decide the combined purse seiners' and blue whiting trawlers' production of unrestricted output. This is in contrast to what Asche *et al.* (2007) found: that the purse seiners seem not to be responsive to changes in the price of the unrestricted outputs. Let it be stressed here that this work is not a replication of Asche *et al.*'s that analyses the behaviour of purse seiners without blue whiting fishing licences, but an application of a similar framework to a segment of the Norwegian purse seiner fleet that fishes blue whiting in addition to herring, mackerel, and capelin. Moreover, our data series runs from 1990 to 2003, while their data series runs from 1992 to 1999. Blue whiting is an important species for the participating vessels, taking up a significant part of their available days at sea, leaving less time to target other non-quota species. The size of the blue whiting vessels, and the engine power required, can explain the importance of the price of fuel on production of unregulated outputs. Thus, the other non-quota species' contribution to the restricted profit can affect to what degree these vessels produce unrestricted outputs.

Table (4.6) presents the elasticities of intensity for the quota-regulated outputs: spring-spawning herring, mackerel and North Sea herring, and capelin. Looking first

Table 4.6: Elasticity of intensity

Restricted outputs	Spring-spawning herring	Mackerel and North Sea herring	Capelin
Variable quantities			
Blue whiting	0.0257	-0.0870	-0.1164***
	(0.0322)	(0.0591)	(0.0327)
Other non-quota species	-0.7844***	2.0989***	-0.2084
	(0.1263)	(0.2180)	(0.5047)
Fuel	-0.1029	0.4516	0.2691***
	(0.2224)	(0.3461)	(0.0475)

at the elasticities associated with blue whiting, for both spring-spawning herring and mackerel and North Sea herring these are not statistically significant, while statistically significant and negative for capelin. This indicates a substitute relationship between blue whiting and capelin.

According to Table (4.1) that shows the different fishing seasons, there is an overlap between the main season for fishing blue whiting on its spawning grounds in the North East Atlantic and fishing for capelin on the coast of Northern Norway, both taking place in winter and early spring. The capelin quotas have changed substantially over the years and the substitute relationship implies that an increase in the capelin quota causes a decrease in the landings of blue whiting. This is reasonable because of the overlap in fishing seasons, because the respective fisheries take place in waters far apart, and both capelin and blue whiting are low-valued species. Specifically, a 1% increase in the capelin quota causes a 0.12% decline in the harvest of blue whiting. This low, but statistically significant, elasticity probably reflects that the expanded fishing capacity makes it possible for the vessels to accommodate substantial increases in the capelin quotas without a similar reduction in the blue whiting harvest[21].

The elasticity associated with other non-quota species with respect to spring-spawning herring is negative and statistically significant. A 1% increase in the quota for spring-spawning herring causes a reduction of 0.78 % in the harvest of other non-quota species,

---

[21] Standal (2006) and Nøstbakken (2006) have documented substantial increases in capacity as well as economies of scale in Norway's pelagic fishing fleet.

implying a substitute relationship between these two fisheries. Looking at the quota effect of mackerel and North Sea herring on other non-quota species, on the other hand, revealed a strong complementary relationship, where a 1% increase in the quotas for mackerel and North Sea herring causes an increase of 2.1% in the harvest of other non-quota species. Because by-catch is not an issue in these fisheries this result needs further explanation. Although other non-quota species are low- value species relative to mackerel and North Sea herring, they are fished in the same waters, *i.e.*, mainly the North Sea and adjacent waters, using the same technology, *i.e.*, purse seine, under the same environmental conditions, and an increase in the quotas for mackerel and North Sea herring increases the time spent in these waters allowing the vessels to catch more of the other non-quota species whenever an opportunity to do so presents itself. Hence, the strong complementarity between mackerel and North Sea herring and other non-quota species. Between other non-quota species and capelin there appears to be no statistically significant relationship.

Asche *et al.* (2007) found the unregulated species to be substitutes for spring-spawning herring, and mackerel and North Sea herring, with almost a one-to-one relationship between mackerel and North Sea herring, and unregulated species. In this work, however, we find that other non-quota species have close to a one-to-one substitute relationship with spring-spawning herring, and are in a strong complementary relationship with mackerel and North Sea herring.

The demand for fuel does not seem to be statistically significant, as affected by changes in the spring-spawning herring, mackerel and North Sea herring quotas. Changes in the capelin quota, on the other hand, have a strong positive, statistically significant effect on the demand for fuel. Specifically, a 1% increase in the capelin quota will be accompanied by 0.27% increase in the purse seiners demand for fuel. The capelin is not only a low-price species but a high-cost fishery too.

Once again according to Table (4.1), it is not just blue whiting and capelin that have an important fishing season in the first months of the year; simultaneously, a substantial part of the quota for spring-spawning herring is caught during the first months of the year. However, spring-spawning herring is also fished in the late autumn, enabling the vessels to fish all, or a part, of their quota either early or late in the year. Thus, it is possible that in years when the winter capelin fishery is open, the vessels concentrate on catching their capelin quota and then switch to blue whiting for the rest of the season, postponing the spring-spawning fishery until autumn. By doing so they are more focused on catching their quotas of mackerel and North Sea herring before fishing for the spring-spawning herring, leaving less time to fish other non-quota species.

Table (4.7) reports the average real prices of spring-spawning herring, mackerel and North Sea herring, and capelin along with their respective shadow values and marginal shadow values. Comparing the prices and the shadow values with the marginal shadow values tells us something of the overall relationship between the non-quota species (*i.e.*, blue whiting and other non-quota species) and the various restricted outputs, as well as the marginal cost of producing the restricted outputs. The shadow values of both spring-spawning herring and capelin, both statistically significant, are higher than their respective marginal shadow values, only statistically significant for spring-spawning herring, but less than the respective prices, suggesting a substitute relationship between the non-quota species and spring-spawning herring and capelin. For mackerel and North Sea herring, on the other hand, the shadow value is higher than the price and higher than the marginal shadow value; these results are statistically significant, indicating a complementary relationship between the unrestricted outputs and mackerel and North Sea herring.

The differences between the prices and marginal shadow values are the marginal costs of catching more of the quota species, holding the landings of the non-quota species constant. For capelin the marginal cost is about 22.3% of the price, but, because the price and the marginal shadow value are not statistically significant, the marginal costs are probably much higher for the majority of observations, and may in fact be higher than the price for some. The low and variable profitability of the capelin fishery is probably

Table 4.7: Prices and shadow values

Restricted outputs	Spring-spawning herring	Mackerel and North Sea herring	Capelin
Prices and values			
Real price	3.2490***	0.8414***	1.0806
	(1.1919)	(0.2138)	(0.9260)
Shadow value	2.8824***	0.9602***	0.4904***
	(0.2229)	(0.0749)	(0.1270)
Marginal shadow value	3.2407***	0.7806***	0.8392
	(0.1885)	(0.0599)	(7036231)

caused by the large volatility in the stock, with highly variable quota levels and prices, and remote fishing location north of Norway and Iceland.

Catching one extra unit of mackerel and North Sea herring comes at an expense of 7.2% of the price. The cost of catching one extra unit of spring-spawning herring, however, is only 0.26% of the price and statistically significant. The relatively low quota levels on mackerel, North Sea herring, and spring-spawning herring and the expanded fishing capacity of the vessels explain the low marginal costs. By exploiting the spare capacity, marginal increases in the quota levels can be accommodated without increasing the number of trips[22].

4.7 Concluding Remarks

Asche *et al.* (2007) found the catch of unrestricted fish to be a substitute for the IVQ-regulated fisheries on spring-spawning herring, mackerel, and North Sea herring, with an almost one-to-one relationship with mackerel and North Sea herring. Moreover, they

---

[22] These marginal costs may seem unreasonably small and a few comments may be required. Firstly, the marginal shadow value focuses only on the change in restricted profits from a change in the quota, holding the unrestricted harvest constant. Thus, the potential gains and losses from changes in the unrestricted outputs that occur when quotas change are not part of the marginal shadow value. Secondly, operation costs can include costs of fuel, wages, insurance, bait and other variable costs. However, in this paper operating costs are identical to fuel expenditure. Because some of the other costs are not reported for all observations, including them in an operating costs index would mean a loss of observations. Because they are only reported as expenditures, it was decided to use fuel expenditure as a proxy for operating costs. Had other variable costs been included, marginal costs would of course have been higher too. Finally, changes in the TACs for the restricted outputs will usually be announced in advance of, or very early in, the fishing season, thus enabling the fishermen to take this into account in their planning and land more fish per trip without having to increase the number of trips.

found only the own price elasticity of operation costs to be different from zero and statistically significant, and, thus, it is not the price of the unregulated species that determines landings and fishing effort for these species. Finally, they claim that IVQs give strong incentives to increase fishing effort, particular when the quotas are reduced.

What Asche *et al.* (2007) called unrestricted catch is comparable to what is called the other non-quota species in this paper, where the purse seiners are licensed to catch blue whiting in addition to other non-quota species, spring-spawning herring, mackerel, North Sea herring, and capelin. Our results for other non-quota species and fuel expenditure differ from Asche *et al.*'s results regarding unrestricted catch and operation costs. We found the catch of other non-quota species to have a close to one-to-one substitute relationship with the quota on spring-spawning herring, and a strong complementary relationship with mackerel and North Sea herring, such that a reduction in the quota for spring-spawning herring would lead to more fishing effort directed towards the other non-quota fisheries, while a reduction in the quotas for mackerel and North Sea herring would be followed by a strong decrease in the catch of other non-quota species. The fishing effort and landings of other non-quota species are responsive to their own price and the price of fuel. Furthermore, the price of other non-quota species seems to have some positive effects on the supply of blue whiting and the demand for fuel.

The catch of blue whiting showed no statistically significant relationships with the quota-regulated species, except for being a substitute for capelin but with far from even a one-to-one relationship. Thus, the quota levels of spring-spawning herring, mackerel, North Sea herring, and capelin seem to have little effect on fishing effort and the catch of blue whiting. What seem to influence blue whiting fishery, however, are the price of other non-quota species and the price of fuel.

Although blue whiting and other non-quota species are all unregulated fisheries, there are clearly differences in the fishermen's behaviour towards the respective species. The blue whiting fishery is not influenced by its own price, and only to some degree affected by the capelin quotas and other factors of production. The other non-quota species, on the other hand, are strongly linked to the spring-spawning herring, mackerel, and North Sea herring fisheries as well as being responsive to their own price and the price of fuel.

References

ÅRLAND, K., AND T. BJØRNDAL (2002): "Fisheries management in Norway - an overview," *Marine Policy*, 26, 307–313.

ASCHE, F., D. V. GORDON, AND C. L. JENSEN (2007): "Individual Vessel Quotas and Increased Fishing Pressure on Unregulated Species," *Land Economics*, 83(1), 41–49.

BJØRNDAL, T., AND D. V. GORDON (2000): "The economic structure of harvesting for three vessel types in the Norwegian spring-spawning herring fishery," *Marine Resource Economics*, 15, 281–292.

BJØRNDAL, T., D. V. GORDON, V. KAITALA, AND M. LINDROOS (2004): "International Management Strategies for a Straddling Fish Stock: A Bio-Economic Simulation Model of the Norwegian Spring-Spawning Herring Fishery," *Environmental & Resource Economics*, 29(4), 435–457.

DAVIDSON, R., AND J. G. MACKINNON (2004): *Econometric Theory and Methods.* Oxford University Press, New York, Oxford.

DIEWERT, W. E. (1974): "Functional Forms for Revenue and Factor Requirement Functions," *International Economic Revue*, 15(1), 119–130.

——— (1982): "Duality Approaches to Microeconomic Theory," in *Handbook of Mathematical Economics*, ed. by K. J. Arrow, and M. D. Intriligator, vol. 2, chap. 12, pp. 535–599. North-Holland Publishing Company, Amsterdam, New York, Oxford.

DIEWERT, W. E., AND L. OSTENSOE (1988): "Flexible Functional Forms for Profit Functions and Global Curvature Conditions," in *Dynamic Econometric Modeling*, ed.

by W. A. Barnett, E. R. Berndt, and H. White, chap. 3, pp. 43–51. Cambridge University Press, Cambridge.

Diewert, W. E., and T. J. Wales (1987): "Flexible Functional Forms and Global Curvature Conditions," *Econometrica*, 55, 43–68.

Dupont, D. P. (1991): "Testing for Input Substitution in a Regulated Fishery," *American Journal Of Agricultural Economics*, 73(1), 155–164.

Dupont, D. P., and D. V. Gordon (2007): "Shadow Prices for Fishing Quota: Fishing with Econometrics," in *Advances in Fisheries Economics - Festschrift in Honour of Professor G.R. Munro*, ed. by T. Bjørndal, D. V. Gordon, R. Arnason, and U. R. Sumaila, chap. 6, pp. 87–106. Blackwell, Oxford.

Ekerhovd, N.-A. (2003): "Spelet om kolmule," SNF Report 34/03. Center for Fisheries Economics, Institute for Research in Economics and Business Administration (SNF), Bergen, Norway.

Fulginiti, L., and R. Perrin (1993): "The Theory and Measurement of Producer Response Under Quotas," *The Review of Economics and Statistics*, 75(1), 97–106.

ICES (2004): "Report of the Northern Pelagic and Blue Whiting Fisheries Working Group," ICES CM 2004/ACFM:24, Copenhagen.

Kohli, U. (1993): "A Symmetric Normalized Quadratic GNP Function and the U.S. Demand for Imports and Supply of Exports," *International Economic Review*, 34(1), 243–255.

Lau, L. J. (1976): "A Characterization of the Normalized Restricted Profit Function," *Journal of Economic Theory*, 12, 131–163.

Leathers, H. D. (1991): "Allocable Fixed Inputs as a Cause of Joint Production: A Cost Function Approach," *American Journal of Agricultural Economics*, 74(4), 1083–1090.

McFadden, D. (1978): “Cost, Revenue, and Profit Functions,” in *Production Economics: A Dual Approach to Theory and Applications*, ed. by M. Fuss, and D. McFadden, vol. 1, chap. I.1, pp. 3–109. North-Holland Publishing Company, Amsterdam, New York, Oxford.

Moschini, G. (1988): “A Model of Production with Supply Management for the Canadian Agricultural Sector,” *American Journal of Agricultural Economics*, 70(2), 318–329.

Nøstbakken, L. (2006): “Cost Structure and Capacity in Norwegian Pelagic Fisheries,” *Applied Economics*, 38, 1877–1887.

Sandberg, P. (2006): “Variable unit costs in an output-regulated industry: The Fishery,” *Applied Economics*, 38, 1007–1018.

Shumway, C. R., R. D. Pope, and E. K. Nash (1984): “Allocatable Fixed Inputs and Jointness in Agricultural Production: Implication for Economic Modeling,” *American Journal of Argricultural Economics*, 66, 72–78.

Squires, D. (1987): “Public regulation and the structure of production in multiproduct industries: an application to the New England otter trawl industry,” *RAND Journal of Economics*, 18(2), 232–247.

——— (1988): “Production technology, costs, and multiproduct industry structure: an application of the long-run profit function to the New England fishing industry,” *Canadian Journal of Economics*, 21(2), 359–378.

Squires, D., and J. Kirkley (1991): “Production quota in multiproduct pacific fisheries,” *Journal of Environmental Economics and Management*, 21(2), 109–126.

Standal, D. (2006): “The rise and decline of blue whiting fisheries - capacity expansion and future regulations,” *Marine Policy*, 30, 315–327.

WENINGER, Q. (1998): "Assessing Efficiency Gains from Individual Transferable Quotas: An Application to the Mid-Atlantic Surf Clam and Ocean Quahog Fishery," *American Journal of Agricultural Economics*, 80(4), 750–764.

WILEY, D. E., W. H. SCHMIDT, AND W. J. BRAMBLE (1973): "Studies of a Class of Covariance Structure Models," *Journal of the American Statistical Association*, 68(342), 317–323.