Working Paper No. 27/10

NON-COOPERATIVE MANAGEMENT OF THE NORTHEAST ATLANTIC COD FISHERY: A FIRST MOVER ADVANTAGE

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SNF Project No. 5181
The effect of political uncertainty in fisheries management:
A case study of the Northeast Arctic cod fishery

The project is financed by the Research Council of Norway

INSTITUTE FOR RESEARCH IN ECONOMICS AND BUSINESS ADMINISTRATION
Bergen, December 2010
ISSN 1503-2140

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Abstract

The point of departure for this analysis is Bjørndal and Lindroos (2011), who developed an empirical bioeconomic model to analyse cooperative and non-cooperative management of Northeast Atlantic cod. In their analysis, only constant strategies were analysed for non-cooperative games. In this paper, non-constant strategies are considered. Moreover, the fishery in question is characterised by cooperative management. What may happen in the real world, is that one nation breaks the cooperative agreement by fishing in excess of its quota. Often, it takes time for the other agent to detect this and respond. In this paper, we allow this kind of delayed response into a two agent non-cooperative game so that, if country 2 exceeds its quota, there will be a time lag before this is detected by country 1; moreover, there may also be a delay until country 1 is able to respond. Results show that the outcome critically depends on the length of these two lags as well as initial conditions.

Introduction

The fishery for Northeast Atlantic cod (*Gadus morhua*) in the Barents Sea is one of the major and most valuable fisheries in the North Atlantic[1]. In some years, annual landings have exceeded one million tonnes; since 2004, they have varied between 490,000 – 640,000 tonnes. After the introduction of Extended Fisheries Jurisdiction, cod is a shared stock between Norway and Russia. The two countries jointly set the Total Allowable Catch (TAC) which is split 50-50, with a given percentage being allocated to third countries. Overfishing of quotas has been a concern for a number of years.

Surveys of the management of shared stocks are provided by Bjørndal and Munro (2007) as well as Bjørndal *et al.* (2000). This analysis is based on an extension of the standard dynamic bioeconomic model to include strategic behaviour between the agents participating in the fishery. Bjørndal and Munro (2007) review both cooperative and non-cooperative games. Legal issues, included those pertaining to the 1995 UN Fish Stocks Agreement, are analysed by Munro *et al.* (2004).

A number of authors have analysed management of the Northeast Atlantic cod stock. Armstrong (1994) uses a cooperative game theoretic model to describe possible solutions for the Russian-Norwegian joint management of this stock. Three different cooperative solutions, as well as cooperative compensated solutions to the problem, are analysed. Based on these solutions, a negotiation framework is established for decision making which is discussed in the setting of Norway and Russia's political and economic environment.

Given that the fishermen harvest different segments of a fish stock, shares allotted may have considerable effect on the wellbeing of the stock and the economics of the fishery. Armstrong (1998) analyses an existing allocation rule defining harvest shares allotted to trawlers and coastal vessels in the Norwegian cod

[1] An important source on this fishery is given by: International Arctic Science Committee (Content Partner); Sidney Draggan (Topic Editor). 2008. "Fisheries and aquaculture in the Northeast Atlantic (Barents and Norwegian Seas)." In: Encyclopedia of Earth. Eds. Cutler J. Cleveland (Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment). [First published in the Encyclopedia of Earth March 29, 2007; Last revised August 29, 2008; Retrieved March 9, 2009]. http://www.eoearth.org/article/Fisheries_and_aquaculture_in_the_Northeast_Atlantic_(Barents_and_Norwegian_Seas)

fishery. Requiring a first best approach to an optimal stock size results in no harvest in the first years studied.

There is also extensive literature on the application of game theory to the Barents Sea cod fishery. Sumaila (1997a) develops a bioeconomic model for two Barents Sea fisheries that attempts to capture the predator-prey relationships between cod and capelin. The aim is to analyse joint (cooperative) versus separate (non-cooperative) management of this predator-prey system with a view to isolating the efficiency loss due to separate management. Results of the study suggest that (i) under current market conditions it is economically optimal to exploit both species (rather than just one of them) under joint management, (ii) in comparison with the separate management outcome, a severe reduction of the capelin fishery is called for under joint management, and (iii) the loss in discounted economic rent resulting from the externalities due to the natural interactions between the species is significant.

Sumaila (1997b) develops a two-agent model – consisting of trawlers and coastal vessels - for the exploitation of the Arcto-Norwegian cod stock to investigate the economic benefits that can be realised from the resource. In the model, conflicts arise mainly from the differences in fishing gear and grounds, and different agegroups of cod targeted by the two agents. Using a game theoretic framework, it is shown that the *optimum optimorum* is obtained under cooperation with side payments and no predetermined harvest shares, in which case the coastal fishery buys out the trawl fishery. However, sensitivity analysis shows that if the price premium assumed for mature cod is taken away, the trawl fishery takes over as the producer of the *optimum optimorum*.

Bjørndal and Lindroos (2011), building on a bioeconomic model due to Hannesson (2007, 2010), analyse cooperative and non-cooperative management of cod under different assumptions including a high and a low cost case and different initial values for the biomass. Cooperative management of the resource was found to give rise to a very high net present value, although it depends on the cost parameters and the initial stock level. A striking result from the analysis is that an optimal policy calls for pulse fishing.

An optimal policy was found to involve effort varying from year to year. This is not realistic because a policy of this nature might impose substantial social costs when the fishery is closed. For this reason, a constant effort policy was also considered, i.e., a policy where a constant fraction of the stock is harvested every year. Constant effort is seen to imply a loss in net present value. This, however, disregards possible social costs implied by effort varying from year to year.

While constant and non-constant strategies were considered for the cooperative case, for non-cooperative games only constant strategies were analysed.

The purpose of this article is to extend Bjørndal and Lindroos (2011) to analyse non-cooperative management of the Northeast Atlantic cod fishery, to consider the case where one of the players has a first mover advantage. This will be done in a game theoretic context, based on different assumptions regarding important variables such as cost of effort and initial stock size. To the best of our knowledge, this is the first time a first mover advantage has been incorporated in an empirical game theoretic model for a fishery.

The paper is organised as follows. The next section gives an overview over stock and catch development over time, while the management of the stock is reviewed in section 3. Bioeconomic modelling is undertaken in section 4, while alternative management regimes are considered in section 5. The results are discussed in the final section. Background biological data are given in the Appendix.

2. Stock development

The Northeast Atlantic cod (*Gadus morhua*) has its main spawning grounds on the coastal banks of Norway between 62º and 70º N and return to the Barents Sea after spawning. Cod, capelin, and herring are considered key fish species in the ecosystem and interactions among them generate changes which also affect other fish stocks as well as marine mammals and birds (Bogstad *et al.*, 1997). Recruitment of cod and herring is enhanced by inflows of Atlantic water carrying large amounts of suitable food for larvae and fry of these species. Consequently, survival increases, so that juvenile cod and herring become abundant in the area. However, since young and juvenile herring prey on capelin larvae in addition to zooplankton, capelin recruitment might be negatively affected and thus cause a temporal decline in the capelin stock, an occurrence that would affect most species in the area since capelin is their main forage fish. Predators would then prey on other small fish and shrimps. In particular, cod cannibalism may increase and thus affect future recruitment of cod to the fishery (Hamre, 2003).

Management advice has been provided by the International Council for the Exploration of the Sea (ICES) from the early 1960s. A variety of conservation measures were recommended in order to increase yield per recruit and to limit the overall fishing mortality. The first TAC for cod was set in 1975, but was far too high. Although minimum mesh size regulations had been in force for some years at that time, it is fair to conclude that no effective management measures were in operation for demersal fish in the area prior to the establishment of the 200 mile Exclusive Economic Zones (EEZs) in 1977.

The Northeast Arctic cod stock has been jointly managed by Norway and Russia (earlier the Soviet Union) since 1977, when the 200-mile Exclusive Economic Zone was established. The primary control instrument is an upper limit on the total catch each year, but other controls such as a minimum mesh size and measures which aim at increasing the yield of the stock are also in place. The total catch quota is shared evenly by Russia and Norway, after setting aside about 15 percent of the total for third countries that have traditionally fished this stock. Most of the quotas given to each country fishing this stock are allocated between boats from the country in question. Norway and Russia monitor the fishing in their respective zones and take measures as they deem required against boats breaking the regulations.

Figure 1 gives annual data[2] on spawning stock size, landings and recruitment to the spawning stock for the period 1946-2007. Right after the Second World War, the stock was at a high level – almost 4.2 mill tonnes in 1946. Although there were substantial fluctuations over time, the trend in stock size was declining until 1980, when it levelled off around 900,000 tonnes for about a decade. Stock size increased in the 1990s to a peak of almost 2.4 mill tonnes in 1993, before falling again. Stock size in 2007 was recorded at 1.7 mill tonnes.

[2] Spawning stock is defined as yearclasses three and older. Landings refer to catches of cod from yearclasses three and older, while recruitment is to the spawning stock.

Landings have fluctuated substantially over time. In the period 1946-54, annual harvest averaged around 800,000 tonnes, increasing to more than 1.3 mill tonnes in 1956, the highest level ever recorded. Landings in excess of 1 million tonnes were also achieved in 1968-69 and 1974, however, this level does not appear to be sustainable, as landings were reduced below 300,000 tonnes in 1983-84. Since 2002, annual landings have varied between 490,000 – 640,000 tonnes.

Recruitment to the stock is highly variable, varying between a low of 37,000 tonnes in 1980 and 700,000 tonnes in 1966.

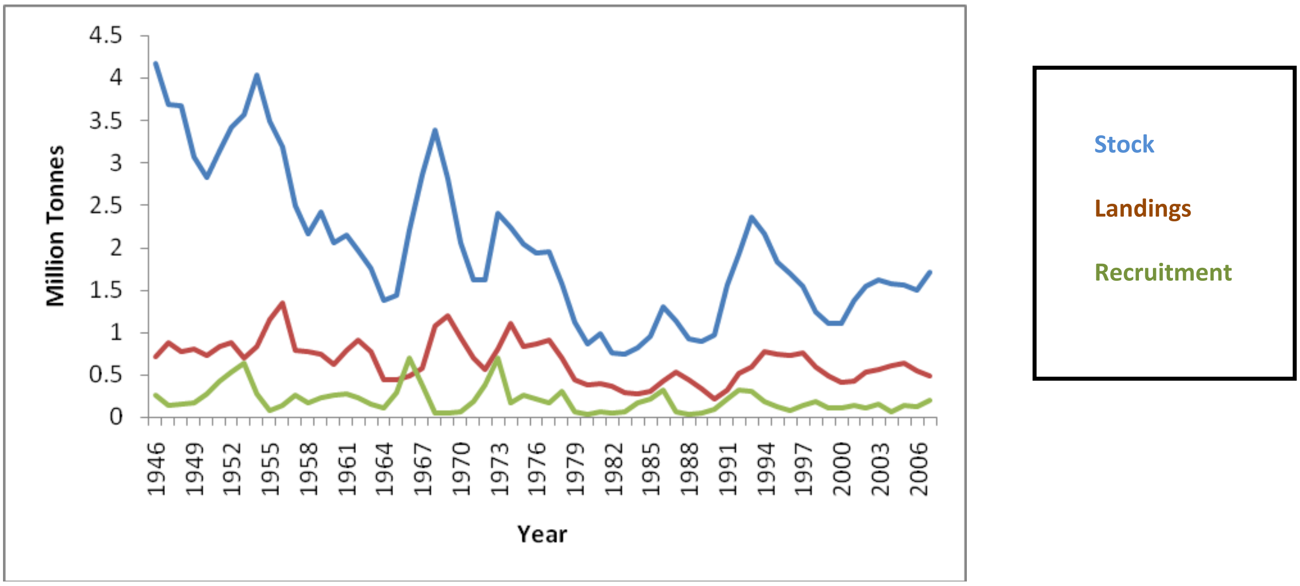

Figure 1. Stock Size, Landings and Recruitment per Year, 1946-2007. Mill. Tonnes.
Source: Appendix, Table A1.

Although Norway and Russia take the largest catches, the fishery for cod is also significant for fishermen from EU countries, especially Spain and the United Kingdom (Bjørndal and Lindroos, 2011). Most of the catch is caught by bottom trawl. The Norwegian quota is caught by vessels using passive fishing gear as well as more active gears such as bottom trawl.

3. Management

A series of agreements has been negotiated among the countries in the Northeast Atlantic that establish bilateral and multilateral arrangements for cooperation on fisheries management. The most extensive management regime in the Northeast Atlantic is that between Norway and Russia. A joint fisheries commission between Norway and Russia meets annually to agree on TACs, thus giving rise to cooperative management. As noted above, the total quotas set are shared between the two countries – the allocation key is 50-50 for cod. A fixed additional quantity is awarded to third countries. The EU is given a major share of the third country quota of cod in the Norwegian waters north of 62º N as witnessed by the catch figures presented in the Appendix, Table A2. Spanish cod trawlers, along with fishing vessels from other EU member countries, fish for cod in the area of Svalbard Islands and Norwegian waters north of 62º north. This activity is conducted under International Agreements (Paris Treaty, EU-Norway Bilateral Agreement), regulating catches as well as conservation measures (TAC system).

An important aspect of the cooperation with Russia is that a substantial part of the Russian harvest in the Barents Sea is taken in the Norwegian zone and landed in Norway. In addition, there is exchange of quotas (Hoel, 1994). The cooperation also entails joint efforts in fisheries research and in enforcement of fisheries regulations.

The cooperation on resource management between Norway and Russia may generally be characterised as well functioning (Hønneland, 1993). However, agreed TACs by Norway and Russia have, in some years, exceeded those recommended by fisheries scientists. In addition, the actual catches have sometimes been larger than those agreed. Since the late 1990s, a precautionary approach has been gradually implemented in the management of the most important fisheries. However, retrospective analyses have shown that ICES estimates of stock sizes have often been too high, thereby incorrectly estimating the effect of a proposed regulatory measure on the stock. This has had the unfortunate effect that stock sizes for a given year are adjusted downward in subsequent assessments, rendering adopted management strategies ineffective (Korsbrekke *et al.*, 2001; Nakken, 1998). However, the Joint Norwegian–Russian Fisheries Commission has decided that from 2004 onwards multi-annual quotas based on a precautionary approach will be applied. A new management strategy adopted in 2003 shall ensure that TACs for any three-year period shall be in line with the precautionary reference values provided by ICES.

The two main elements of the Norwegian fisheries management system are restricting access through licensing schemes and restricting the harvesting through quotas (Årland and Bjørndal, 2002). There are also regulations of minimum mesh size, fish size etc. Capacity is restricted through licensing schemes in the trawler fleet. Some segments of the coastal fleet are subject to licensing; others to open access. A license is issued to a particular owner and a particular vessel and is not transferable. If a vessel is sold or replaced by a new one, a transfer of fishing license must be approved. Most vessels hold more than one license.

The quota restrictions are as follows. First, a Total Allowable Catch (TAC) is fixed, based on advice from ICES (most stocks are shared stocks). Second, the Norwegian quotas are then distributed among the main segments of the fishing fleet as group quotas*.* The trawler fleet are allocated Individual Vessel Quotas (IVQs) for the Northeast Atlantic cod. The IVQs vary from year to year andcan be harvested freely during the year. Conventional (gear) offshore vessels are allocated IVQs too. Maximum quotas, giving maximum catch per vessel, dominate for the coastal fleet. The coastal fleet is often what is called "overregulated". This means that the sum of the vessels' maximum quotas exceeds the group quota allocated to the coastal vessels.

Accordingly, different vessel groups are active in this fishery. Asche, Bjørndal and Gordon (2009) analysed actual rent and potential rent in a trawler fleet harvesting cod. They found that actual rent at the end of the 1990s was negative, however, if the fleet was restructured by reducing excess capacity, potential rent was quite substantial. As far as we know, similar studies have not been undertaken for other vessel groups.

The total TAC for cod has not always been effectively implemented. Norway exceeded its allocated quota for a number of years after the joint Soviet–Norwegian control was put in place, because the agreement permitted Norwegian boats other than trawlers to continue fishing even if the Norwegian allocation had been taken. This problem has been minor or non-existing since the late 1980s. Unauthorised boats, mainly Icelandic, have also at times fished in an area called the Loophole outside the Norwegian and Russian EEZs, but this problem has also largely disappeared since an agreement with Iceland was reached in 1999.

Until recently, Norwegian investigations have indicated that Russia has exceeded its quota by perhaps as much as 100,000 tonnes per year, for an unknown number of years. The problem appears to be lax control of Russian trawlers fishing in the Russian zone. Monitoring catches has been made difficult *inter alia* by transfers of fish at sea (Hannesson, 2007). The situation may, however, be improving. According to industry sources, there was a substantial reduction in illegal landings from 2007 to 2008. Moreover, national quotas were not exceeded in 2009[3]. Whether this improvement in circumstances will continue, remains to be seen.

4. Bioeconomic Modelling

We will base the analysis on an underlying empirical bioeconomic model, namely the one developed by Hannesson (2007, 2010). We specify the following harvest function:

$$H_t = qE_tX_t \qquad (1)$$

where H_t is harvest, E_t is effort and X_t is stock size in year t, while q is the catchability coefficient. Net revenue from the fishery in year t, π_t, is given by

$$\pi_t = pH_t - cE_t \qquad (2)$$

where p is price and c is the constant unit cost of effort.

In bionomic equilibrium (Bjørndal and Munro, 1998), stock size is given by $X_\infty = c/(pq)$.

Following Hannesson (2010), parameters are normalised so that p = q = 1, implying that

$X_\infty = c$,

where c is bionomic equilibrium or the break even stock level. In other words, it is not profitable to reduce the stock below c. Consequently,

$$H_t = E_tX_t \qquad (3),$$

[3] See: http://www.ices.dk/committe/acom/comwork/report/2010/2010/cod-arct.pdf.

so that E_t represents the proportion of the stock harvested. Accordingly, E_t must lie between zero and one.

Hannesson (2010) provides the following point estimate:

c = 2,500.

This means that the stock will never be reduced below 2,500, which corresponds to a stock size of 2.5 million tonnes.

The fact that the cod stock consists of many year classes of fish implies that the development of the stock from one year to the next is largely determined by its size and the amount of fish caught. Hannesson (2010) considered the following specification:

$$X_{t+1} - R_{t+1} = a(X_t - H_t) - b(X_t - H_t)^2, \qquad (4)$$

where R_t is the recruitment of a new year class of fish in year t, and H_t is the landings of fish in year t.

Hannesson (2010) estimated the model for data for 1946–2005 and obtained the following parameter estimates:

a = 1.558

b = 0.000145.

Hannesson (2010) found only a weak relationship between spawning stock size and recruitment. He did, however, find strong serial correlation in recruitment, and estimated the following function:

$$R_t = a_0 + a_1R_{t-1} + a_2R_{t-2} + a_3R_{t-2}$$

The following point estimates were obtained: a_0=144.4; a_1=0.616; a_2=-0.2279; a_3=-0.0863. This empirical model will be employed in the analysis to follow.

Under *natural conditions*, i.e., with no fishing, stock size will approach the carrying capacity of the environment. This is estimated at 4.189 million tonnes, more than double the current level. It is interesting to note that this is close to estimated stock size for 1946, the highest level observed in the data series (Appendix, Table A1).

5. Analysis of Non-Cooperative Management

As described above, the Northeast Atlantic cod is shared between Norway and Russia, with a small quantity going to third countries. We will here assume there are two players in the fishery, Norway and Russia. We specify the following initial values for X_1 and R_1, which represent initial stock size and initial recruitment, respectively:

X_1 = 1.7 million tonnes or

X_1 = 3.3 million tonnes.

R_1 = 203.699 million tonnes

The 2007 stock size is estimated at 1.7 million tonnes (Table A1). As this is a somewhat low level, we will see what difference, if any, it would be to start out at a higher stock level, which is here set at 3.3 million tonnes. R_1 is set at the 2007 value, the most recent estimate available (Appendix, Table A1).

We will consider two alternatives with regard to cost parameters:

1) High costs: $c_1 = c_2 = 2{,}500$

2) Low costs: $c_1 = c_2 = 1{,}400$

These cases thus represent alternative values for stock size in bionomic equilibrium.

As noted, the fishery in question is characterised by cooperative management. What may happen in the real world, is that one nation may break the cooperative agreement by fishing in excess of its quota. This has also been the case for cod. Often, it takes time for the other agent to detect this and respond.

In this analysis, we assume that the fishery at the outset is characterised by cooperation. Then country 2 starts playing non-cooperatively. This will, however, be noticed by country 1 only with a time lag. In the period before the cheating is noticed, country 1 will continue playing cooperatively. Once country 1 discovers the cheating it will react, and both countries play non-cooperatively. The game lasts for 20 years.

As mentioned above, Bjørndal and Lindroos (2011) analysed cooperative and non-cooperative management of this fishery. Some of their results will be used here for purposes of comparison. In the case of cooperative management, two cases were considered: i) constant effort over time and ii) variable (optimal) effort over time. The second case was found to give rise to a much higher net present value from the fishery than the first.

We will here make reference to results from the constant effort case, as this is more directly comparable to the results to be presented here.

High initial stock level

Results regarding the optimal time to detect cheating for the high cost case and a starting value of the stock of 3.3 million tonnes are given in Table 1. The results for the case of a zero time lag are taken from Bjørndal and Lindroos (2011). It is for a non-cooperative game that is solved as a one-shot game where, in the beginning of the game, the two countries choose their fishing efforts that are employed for the rest of the game. The equilibrium is found when optimal effort remains unchanged for the two players. For the case under consideration, each country chooses an effort level of 0.12. Total NPV is NOK 1,364 million, with equilibrium stock size at 3.015 million tonnes. We consider this a base case, for the purposes of comparison.

For the case of cooperative management with constant effort, Bjørndal and Lindroos (2011) found optimal combined effort to be 0.18. The combined NPV is NOK 1,569 million with a steady state stock of 3.46 million tonnes.

E1 and E2 refer to effort levels of players 1 and 2, respectively. Except for the case of a zero lag, there are two entries for each player. The first entry (effort) of each player refers to the cheating period. Here player two chooses the non-cooperative effort, whereas player one chooses cooperative effort. The second entry refers to the phase where both players play non-cooperatively.

Table 1. Non-cooperative game with a first mover advantage for country two. X_1 = 3.3 million tonnes. $c_1 = c_2$ = 2,500.

Lag	Coopera-tive solution	0	1	**2**	3[a]	5	8	12	17
E1	0.09	0.12	0.09, 0.10	0.09, 0.11	0.09, 0.11	0.09, 0.11	0.09, 0.11	0.09, 0.12	0.09, 0.14
E2	0.09	0.12	0.2, 0.12	0.16, 0.11	0.14, 0.12	0.13, 0.12	0.13, 0.12	0.13, 0.12	0.13, 0.15
E1+E2	0.18	0.24	0.29, 0.22	0.25, 0.22	0.23, 0.23	0.24, 0.23	0.22, 0.23	0.22, 0.24	0.24, 0.29
NPV1	784.5	682	600	**674**	641	651	637	626	609
NPV2	784.5	682	820	775	786	796	823	835	862
NPV1+ NPV2	1,569	1,364	1,420	1,449	1,427	1,447	1,460	1,46	1,47
Stock	3,460	3,015	3,177	3,177	3,099	3,099	3,099	3,027	3,194

a) Results for a lag of four periods are the same as for three periods.

Note: Optimal time to detect cheating is bolded (given that lag > 0).

For example with a lag of 2, it takes two periods for player 1 to detect non-cooperative fishing of country two. In the first phase player 1 chooses effort level 0.09, or half of the jointly optimal effort, while player 2 chooses 0.16, knowing the lag and the choice of country 1. After two periods they both play non-cooperatively and choose 0.11 as their efforts. For this case, NPVs for countries 1 and 2 are NOK 684 and 775 million, respectively.

In the base case, country 1 has a NPV of NOK 682 million. Cheating by country 2 leads to a reduction in country 1's NPV, as one would expect. For country 1 it is "optimal" to detect cheating after two periods, as this would give the highest NPV for all alternatives with regard to cheating.

For country 2, the situation is the opposite. Without cheating, the non-cooperative NPV2 is NOK 682 million. With cheating, country 2 always obtains a higher NPV, as one would expect. For some scenarios, it is also higher than payoff in cooperative equilibrium.

Table 2 presents results for the low cost case and a high starting value for the stock. In this case, cooperative management entails a combined effort of 0.26, a combined NPV of NOK 3,848 million and a stock of 2.843 million tonnes. The non-cooperative game, on the other hand, gives rise to a combined effort of 0.34, a joint NPV of NOK 3,338 million and a stock size of 2.045 million tonnes.

The results show that country 2 is always better off with the first mover advantage, but never better off than under cooperation. Country 1, on the other hand, is worse off. The "optimal" time of detection for country 1, in the sense of yielding the highest net present value, is after 12 years.

Table 2. Non-cooperative game with a first mover advantage for country two. X_1 = 3.3 million tonnes. $c_1 = c_2$ = 1,400.

Lag	Cooperative Solution	0	1	2	3	5	8	**12**	17
E1	0.13	0.17	0.13,0.14	0.13,0.15	0.13,0.15	0.13,0.15	0.13,0.15	0.13,0.16	0.13,0.21
E2	0.13	0.17	0.49,0.14	0.31,0.15	0.25,0.15	0.23,0.15	0.2,0.15	0.18,0.16	0.18,0.21
E1+E2	0.26	0.34	0.62,0.28	0.44,0.3	0.38,0.3	0.36,0.3	0.33,0.3	0.31,0.32	0.31,0.42
NPV1	1,924	1,669	1,363	1,473	1,521	1,517	1,531	**1,569**	1,529
NPV2	1,924	1,669	2,127	2,013	2,012	2,016	1,999	2,028	2,078
NPV1 +NPV2	3,848	3,338	3,490	3,486	3,533	3,533	3,530	3,597	3,607
Stock	2,843	2,045	2,653	2,457	2,457	2,457	2,457	2,272	1,868

Note: Optimal time to detect cheating is bolded (given that lag > 0).

Low initial stock level

Table 3 presents results for the high cost case and a low starting value of 1.7 million tonnes for the stock. In this case, cooperative management entails a combined effort of 0.14, a joint NPV of NOK 816 million and a stock of 3.692 million tonnes. On the other hand, the non-cooperative game gives rise to a combined effort of 0.20 with a combined NPV of NOK 680 million and a stock size of 3.325 million tonnes.

With high costs are high and low initial stock, joint profits in non-cooperation are higher because the non-cooperative strategy includes a period when county 2 "cheats" by choosing zero effort to rebuild the stock (up to lag=5). When lag is more than five periods, joint non-cooperative profits start to decline.

The results show that country 2 in all cases gain from the first mover advantage. Moreover, country 2 is always better off than in the cooperative solution.

For many scenarios, NPV1 is better than the cooperative solution for many scenarios. This is for the same reason is given above, namely, country 2 unilaterally rebuilds the stock.

It can be noted that NPV1 is greater than NPV2 for a time lag of 5. This is a pure coincidence.

Table 4 presents results for the low cost case and a low starting value for the stock. In this case, cooperative management entails a combined effort of 0.22, a joint NPV of NOK 2,699 million and an equilibrium stock of 3.177 million tonnes. The non-cooperative game gives rise to a combined effort of 0.30, a combined NPV of NOK 2,266 million and a stock of 2.456 million tonnes.

Also in the low cost case, the stock is rebuilt. For the initial phase, E2 = 0 for time lags of 1 and 2. However, the stock is rebuilt to a lower level than in the high cost case (table 3). Joint profits are higher than under non-cooperation (zero lag), but always less than under cooperation. Country 2 gains from the first mover advantage, but NPV2 is higher than under cooperation only for very long lags. For up to five lags, NPV1 is larger than NPV2 as a consequence of low effort by country 2 in order to rebuild the stock.

Table 3. Non-cooperative game with a first mover advantage for country two. X_1 = 1.7 million tonnes. $c_1 = c_2 = 2{,}500$.

Lag	Cooperative Solution	0	1	2	3	**5**	8	12	17
E1	0.07	0.1	0.07, 0.09	0.07, 0.11	0.07, 0.11	0.07, 0.12	0.07, 0.13	0.07, 0.13	0.07, 0.17
E2	0.07	0.1	0, 0.11	0, 0.11	0, 0.11	0, 0.12	0.04, 0.13	0.08, 0.13	0.09, 0.17
E1+E2	0.14	0.2	0.07, 0.2	0.07, 0.22	0.07, 0.22	0.07, 0.24	0.11, 0.26	0.15, 0.26	0.16, 0.34
NPV1	408	340	351	430	430	**496**	455	389	358
NPV2	408	340	497	497	497	492	430	417	441
NPV1 +NPV2	816	680	748	927	927	988	885	806	799
Stock	3,692	3,325	3,325	3,178	3,178	3,018	2,856	2,893	2,774

Note: Optimal time to detect cheating is bolded (given that lag > 0).

Table 4. Non-cooperative game with a first mover advantage for country two. X_1 = 1.7 million tonnes. $c_1 = c_2 = 1,400$.

Lag	Cooperative Solution	0	1	2	**3**	5	8	12	17
E1	0.11	0.15	0.11, 0.15	0.11, 0.16	0.11, 0.16	0.11, 016	0.11, 0.17	0.11, 0.18	0.11, 0.24
E2	0.11	0.15	0, 0.15	0, 0.16	0.04, 0.16	0.09, 0.16	0.13, 0.17	0.14, 0.18	0.15, 0.24
E1+E2	0.22	0.3	0.11, 0.3	0.11, 0.32	0.15, 0.32	0.2, 0.32	0.24, 0.34	0.25, 0.36	0.26, 0.48
NPV1	1,344	1,133	1,283	1,343	**1,375**	1,306	1,187	1,157	1,105
NPV2	1,344	1,133	1,250	1,225	1,235	1,251	1,324	1,371	1,458
NPV1 +NPV2	2.688	2,266	2,533	2,568	2,610	2,557	2,511	2,528	2,563
Stock	3,177	2,456	2,458	2,258	2,265	2,267	2,085	1,982	0,963

Note: Lag = 3 same as lag = 4 here

Note: Optimal time to detect cheating is bolded (given that lag > 0).

6. Discussion

The point of departure for this article is to extend Bjørndal and Lindroos (2011) to analyse non-cooperative management of the Northeast Atlantic cod fishery, for the case where one of the players has a first mover advantage. This was done in a game theoretic context. In the model, we let country 2 exceed its quota, however, there is a time lag before country 1 detects this and is able to react.

This situation is fairly common, in fisheries as well as other sectors of the economy. Nevertheless, to the best of our knowledge, this the first empirical analysis of a first mover advantage in a fisheries context.

The analysis gave very interesting results. It was demonstrated that initial conditions – high versus low initial stock level – had an impact on the results. With a high initial stock level, equilibrium stock level is always lower than the initial. On the other hand, with a low initial stock level, the equilibrium stock level is generally higher than the initial.

Country 2, which has the first mover advantage, always gains from cheating. In some cases its net present value is even higher than in cooperative equilibrium.

For country 1, the outcome very much depends on initial conditions with respect to stock level as well as high vs. low costs. As would be expected, country 1 looses under many, if not most, scenarios. There is, however, an interesting exception: when the initial stock level is low, country 2 will reduce effort for a period of time in order to rebuild the stock, and country 1 will gain from this.

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APPENDIX: BIOLOGICAL DATA

Table A1. Annual Adult Stock Size, Landings and Recruitment 1946-2007. Tonnes.

	Stock	Landings	Recruitment
1946	4,168,882	706,000	254,849
1947	3,692,801	882,017	136,099
1948	3,665,819	774,295	150,481
1949	3,065,111	800,122	173,289
1950	2,830,103	731,982	274,914
1951	3,141,009	827,180	433,501
1952	3,407,679	876,795	524,969
1953	3,557,376	695,546	636,151
1954	4,039,204	826,021	282,297
1955	3,488,383	1,147,841	87,289
1956	3,189,831	1,343,068	145,069
1957	2,495,895	792,557	265,578
1958	2,164,149	769,313	168,920
1959	2,415,826	744,607	239,291
1960	2,050,805	622,042	268,482
1961	2,137,149	783,221	284,221
1962	1,957,006	909,266	233,068
1963	1,747,579	776,337	151,061
1964	1,374,529	437,695	111,764
1965	1,440,693	444,930	295,238
1966	2,198,418	483,711	696,327
1967	2,852,164	572,605	375,671
1968	3,387,455	1,074,084	54,435
1969	2,805,591	1,197,226	49,297
1970	2,057,698	933,246	72,929
1971	1,610,969	689,048	182,148
1972	1,621,485	565,254	385,821
1973	2,401,955	792,685	691,201
1974	2,236,387	1,102,433	167,653
1975	2,037,430	829,377	254,863
1976	1,931,396	867,463	214,880
1977	1,950,748	905,301	170,547
1978	1,576,565	698,715	312,860
1979	1,114,381	440,538	69,471
1980	863,862	380,434	37,188
1981	983,658	399,038	73,926
1982	750,871	363,730	56,177
1983	738,675	289,992	61,727
1984	817,596	277,651	167,089
1985	957,513	307,920	216,277
1986	1,294,448	430,113	323,074

1987	1,126,275	523,071	60,419
1988	915,458	434,939	43,385
1989	890,359	332,481	51,662
1990	962,672	212,000	96,614
1991	1,561,711	319,158	213,302
1992	1,912,190	513,234	317,280
1993	2,359,674	581,611	307,844
1994	2,155,298	771,086	190,449
1995	1,825,929	739,999	132,065
1996	1,686,862	732,228	85,405
1997	1,532,187	762,403	144,619
1998	1,230,183	592,624	183,376
1999	1,101,326	484,910	111,306
2000	1,101,505	414,868	117,611
2001	1,375,566	426,471	147,741
2002	1,542,075	535,045	110,714
2003	1,608,810	551,990	155,977
2004	1,565,794	606,445	74,315
2005	1,555,835	641,276	135,219
2006	1,496,200	537,642	128,094
2007	1,700,760	486,883	203,699

Source: http://www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=28