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Non-Cooperative Management of the Northeast Atlantic Cod Fishery: A First Mover Advantage

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by

Trond Bjørndal and Marko Lindroos

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Non-Cooperative Management of the Northeast Atlantic Cod Fishery: A First Mover Advantage[1]

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Abstract

The point of departure for this analysis is Bjørndal and Lindroos (2012), 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.

[1] We thank Nils Arne Ekerhovd Stein Ivar Steinshamn for comments.

1. 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. 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). Overfishing of quotas has been a concern for a number of years.

Bjørndal and Lindroos (2012), building on a bioeconomic model due to Hannesson (2007, 2010), analyse cooperative and non-cooperative management of cod under different assumptions. Cooperative management of the resource was found to give rise to a very high net present value of rents, 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. 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 analyse the concept of first mover advantage in a non-cooperative game. We will do so in terms of a case study, namely by extending the analysis of Bjørndal and Lindroos (2012) of 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 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. As such, the analysis is of general interest.

A closely related literature is the analysis of trigger strategies and timing of cooperative agreements. Kaitala and Pohjola (1988) analyse the use of trigger strategies as a means to achieve cooperation. They point out that the timing when cheating is detected is of crucial importance in the effectiveness of trigger strategies.

Kaitala and Lindroos (2004) analyse the timing of cooperative agreements. They study several issues that determine when the players find it optimal to sign agreements. The current paper looks at the timing from a different perspective: when it is optimal to detect cheating. Further game theory modeling is discussed in a recent review by Bailey *et al*. (2010).

Numerous studies address a wide range of fishery management issues in the Barents Sea (Diekert *et al.*, 2010b). Recent studies on non-cooperative management include Ekerhovd (2013), Bjørndal and Lindroos (2012) and Diekert *et al*. (2010a). Of these, Ekerhovd (2013) analyses how an increase in the productivity of the North-East Arctic cod fishery affects Russian–Norwegian cooperation on fish stock management, allowing for non-constant non-cooperative strategies, Diekert *et al.* (2010b) highlight the importance of age- and gear-specific modelling in fishery economics, while Bjørndal and Lindroos (2012) analyse cooperative management for different cost parameters and starting values of the stock, and constant strategies for the non-cooperative management.

The paper is organised as follows. The next section gives an overview over stock and catch development as well as a review of the management of the stock. Bioeconomic modelling is undertaken in section 3, while alternative management regimes are considered in section 4. The results are discussed in the final section.

2. Stock development and management[2]

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.

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.

Right after the Second World War, the spawning stock was at a high level – almost 4.2 mill tonnes in 1946. This high level was presumably due to the low incidence of fishing during the war. Subsquently, 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.

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

[2] This section is largely based on Bjørndal and Lindroos (2012).

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.

A joint fisheries commission between Norway and Russia meets annually to agree on TACs, thus giving rise to cooperative management. 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. The cooperation also entails joint efforts in fisheries research and in enforcement of fisheries regulations.

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).

3. Bioeconomic Modelling

We will base the analysis on an empirical bioeconomic model due to 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, stock size is given by

$X_\infty = c/(pq) = c$,

with parameters normalised so that p = q = 1 (Hannesson, 2010), implying that c is bionomic equilibrium or the break-even stock level. In other words, it is not profitable to reduce the stock below c. Consequently,

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

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.

Hannesson (2010) estimated the following specification of stock dynamics for data for 1946-2005:

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

where R_t is the recruitment of a new year class of fish in year t, and obtained the following parameter estimates of a = 1.558 and b = 0.000145.

As the cod follows what biologists call r-strategy with many offspring whereof few survive, as opposed to k-strategy with few offspring that are taken well care of like e.g. humans, we cannot expect to find any significant releationship between the number of eggs and subsequent recruitment of young cod. Each cod lays millions of eggs, but only a few them live up. Therefore survival conditions are much more important than the number of eggs, and to the best of our knowledge, no one has found any significant stock-recruitment relationship for cod empirically. 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, although fairly simple, gives a good fit of the data and will serve our purposes for the analysis to follow.

Under *natural conditions*, i.e., with no fishing, stock size will approach the carrying capacity of the environment. Bjørndal and Lindroos (2012) estimated the carrying capacity to be 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, when the stock could be expected to be at maximum level as the resource was largely unexploitd during the second world war. This is also the highest stock level observed in the data series.

4. Analysis of Non-Cooperative Management

As noted in the background section, 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 situation, which is known in many contexts, has also been the case for cod. Moreover, often it takes time for the other agent, first to detect this and second, to 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 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. 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 (Bjørndal and Lindroos, 2012).

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 mentioned above, Bjørndal and Lindroos (2012) 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.

<u>High initial stock level</u>

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 second column represents the case of cooperative management with constant effort, where Bjørndal and Lindroos (2012) 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. The third column gives the results for 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 which is also taken from Bjørndal and Lindroos (2012). 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.

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	Non-cooperativesolution	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, in the sense that 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	Non-cooperative solution	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	Non-Cooperative Solution	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	Non-cooperative Solution	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).

5. Discussion

The point of departure for this article is to extend Bjørndal and Lindroos (2012) 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.

The article gives important knowledge not only about management of cod in the North Atlantic, but also about first mover advantages in general. As such, it adds to the literature on trigger strategies and, in particular, provides insights as to when it is optimal to detect cheating. The possibility to start cooperating again, after some periods with non-cooperative behavior, has not been considered but would represent an interesting extension of the analysis.

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