SNF Working Paper No. 54/06

CHEATING ABOUT THE COD

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SNF Project No. 5255: "Strategic Program in Resource Management"
The project is funded by The Research Council of Norway

INSTITUTE FOR RESEARCH IN ECONOMICS AND BUSINESS ADMINISTRATION
BERGEN, DECEMBER 2006
ISSN 1503-2140

Abstract

The Northeast Arctic cod is managed by a total quota shared evenly between Norway and Russia. It appears that Russia has been overfishing its quota by substantial amounts for a number of years, due to insufficient monitoring of fishing vessels. This paper considers what would be the best reply by Norway to given levels of Russian overfishing. It is found that in most cases the best Norwegian reply would be also to overfish its quota. An aggregate biomass model with stochastic growth and recruitment is used to analyze this question, with parameters estimated from 1946-2005 data. Recruitment is serially correlated but apparently independent of the spawning stock. A model using the estimated serial correlation in recruitment and a random disturbance is capable of reproducing recruitment patterns similar to the irregular pattern observed since 1946.

December 2006

INTRODUCTION

This paper is inspired by the overfishing of the Northeast Arctic cod. This fish stock has been jointly controlled 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 other 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.

The total quota 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 Soviet-Norwegian agreement permitted Norwegian boats other than trawlers to continue fishing even if the Norwegian allocation had been taken. This problem has been minor or nonexisting since the late 1980s. Unauthorized boats have also at times fished in an area called the Loophole outside the Norwegian and Russian 200 mile zones, but this problem also has largely disappeared since an agreement with Iceland, the main culprit, was reached in 1999.

Lately, 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. The problem has been acknowledged by the Russian authorities, but there is no agreement on its magnitude.

What would be the appropriate reaction by Norway to these events? Would it be better off by sticking to its share of the agreed quota, or should it retaliate by exceeding its own quota in a similar manner? In this paper this problem is studied with a simple, aggregate biomass model of the cod stock. Three strategies are compared, (i) a cooperative strategy where the rents of optimal fishing are shared evenly between the two countries, (ii) fishing in excess of the Russian share of the quota, and (iii) the best possible reaction by Norway to any given Russian overfishing. For simplicity, the participation of third countries in this fishery is ignored. Both countries are assumed to have the same fishing costs.

A MODEL OF THE NORTHEAST ARCTIC COD

For stock assessment purposes, age-structured models are used for the Northeast Arctic cod. While more realistic, such models are also much more complex than aggregate biomass models. Furthermore, age-structured models introduce idiosyncratic elements of uncertainty, as parameters such as weight at age and natural mortality are not constant but variable and known only after the fact and with some uncertainty. The gains in validity from age-structured models compared with aggregate biomass models will therefore be smaller than if their parameters were known with full certainty. This, and the fact that aggregate biomass models are computationally much simpler, is an argument for using them when they can be reconciled with reality.

The fact that the 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. One possible specification of this is

$$(1) \qquad X_{t+1} - R_{t+1} = a\left(X_t - Y_t\right) - b\left(X_t - Y_t\right)^2$$

where X_t is the stock at the beginning of year t, R_t is the recruitment of a new year class of fish in year t, and Y_t is the landings of fish in year t.[1] Estimating the coefficients from data for 1946-2005 gave the results shown in Table 1.[2]

Table 1

Results of estimating the coefficients in Equation (1), with a constant (a_0) added, from data for 1946-2005. Numbers in parentheses are t-values. Numbers in last row are estimates without a constant and used in the paper.

a_0	a	b	R^2	*D-W statistic*
69.7 (0.64)	1.4648 (9.87)	0.0001203 (2.88)	0.94	2.27
0	1.5550	0.0001438		

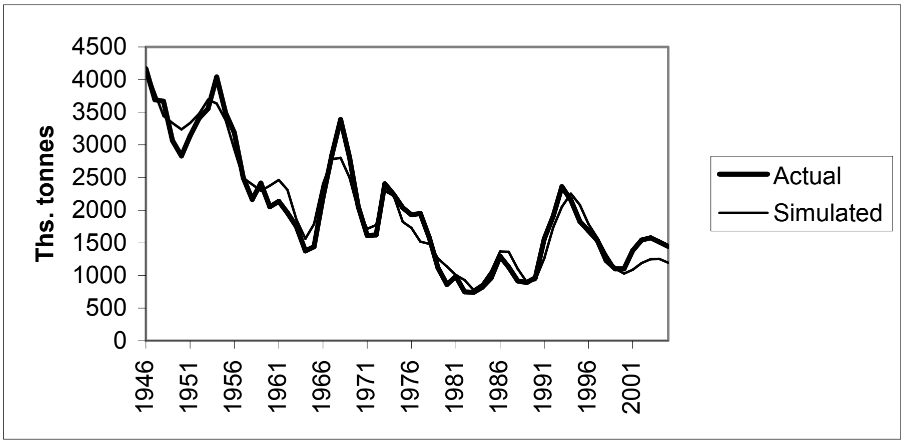

Figure 1: Actual and simulated development of the Northeast Arctic cod.

The growth equation fits the growth of the stock very well, and the Durbin-Watson statistic indicates that serial correlation is not a problem. Figure 1 shows a simulation of the stock, using the estimated growth parameters, the actual recruitment, and the rate of exploitation (*Y/X*) observed in any year. The model tracks the stock development quite well. The largest discrepancy occurs for the last five years, which is perhaps not a problem, as stock estimates are retrospective and improve with time.

[1] This amounts to treating growth and natural mortality as occurring after fishing has taken place.

[2] The data are from ICES (2006). The data comprise the stock size at the beginning of each year and landings over the year, from which we can calculate the stock left after fishing, ignoring growth and natural mortality during the year. Data on R are in weight, not numbers.

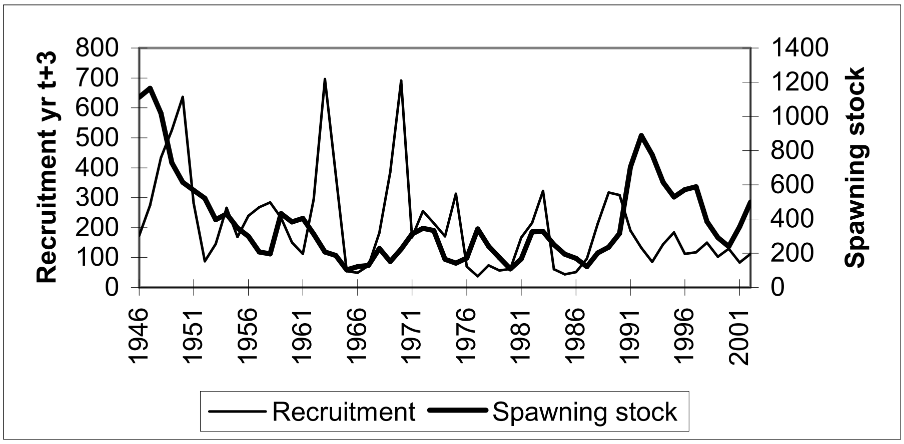

Figure 2: Spawning stock and recruitment 3 years later (ths. tonnes).

The downward decline of the stock is due to an increasing rate of exploitation, while the recurring peaks in the stock are due to variable recruitment of young fish. The fish are considered recruited into the stock at the age of 3. Figure 2 shows the recruitment to the stock and the size of the spawning stock. Three features are particularly remarkable. First, the very large recruitment peaks that occasionally occurred appear to be a thing of the past; the last big peaks occurred in the 1960s, and even if recruitment is still variable, it has been much less so over the last 30 years. Second, the exceptionally large recruitments in the 1960s were produced by a spawning stock that was not remarkably large. Since the early 1990s the spawning stock has been almost as large as in the first years after the Second World War, but this has not resulted in improved recruitment. If anything, the recruitment to the stock has stabilized at a rather low level.

Third, there is clearly a serial correlation in the recruitment. Regressing recruitment on its lagged values produced the results in Table 2. The coefficients of the first two lagged terms are significant, but not the third one.

Table 2

Results of estimating the equation $R_t = a_0 + a_1R_{t-1} + a_2R_{t-2} + a_3R_{t-3}$. Significance at the 1 (5) percent level is denoted by ** (*). Numbers in parentheses are t-values.

a_0	a_1	a_2	a_3	R^2
134.3** (4.20)	0.6438** (5.01)	-0.2897** (-2.24)		0.29
145.8** (3.86)	0.6199** (4.52)	-0.2373 (-1.51)	-.0831 (-0.61)	0.28

The apparent absence of correlation between the spawning stock and recruitment is illustrated by Figure 3. There is a weak indication that a too large spawning stock might be counterproductive, as already suggested by Figure 2; fitting a parabolic equation to the data produces a negative but insignificant coefficient for the squared term. The most reasonable interpretation of this scatter plot is that any relationship between the size of the spawning stock and recruitment is dwarfed by variability in the environment. The variability of recruitment is not well understood, but is apparently due to availability of food at a critical stage in the life of eggs and larvae. The variations in this are caused by or coincide with variations is ocean currents and temperature. Obviously there is some critical lower limit at which recruitment is seriously hampered by a small spawning stock, but it is not known what that limit is, and if it were, this fishery would indeed be in trouble.

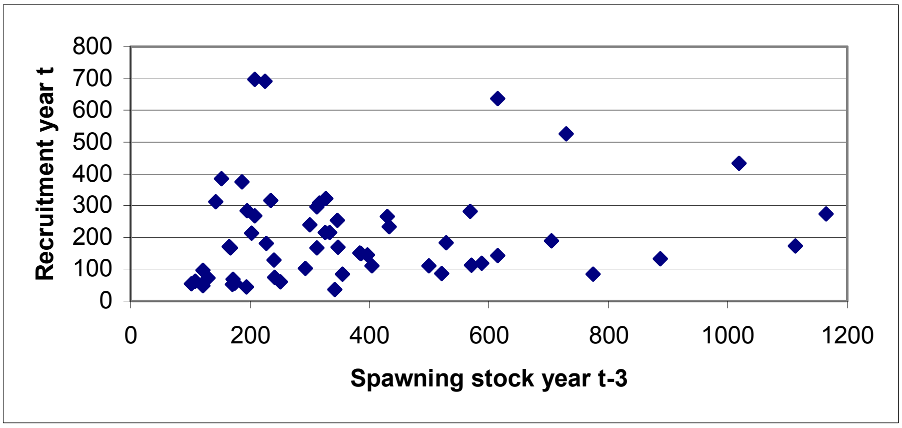

Figure 3: Plot of recruitment against spawning stock three years earlier.

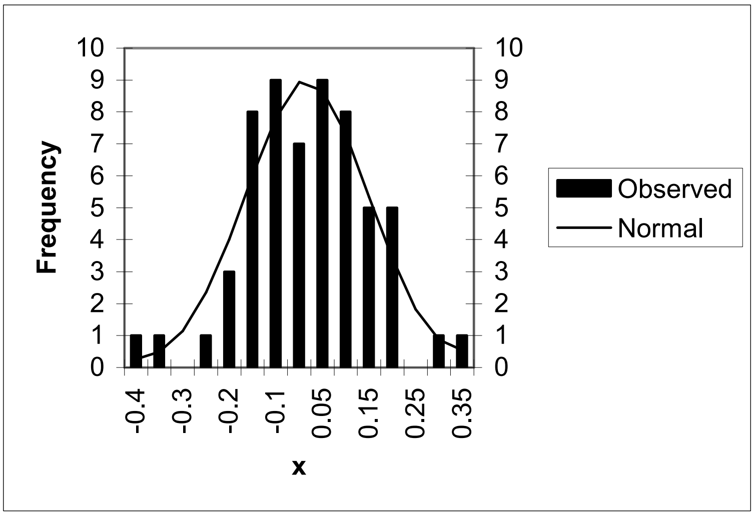

Figure 4: Distribution of the transformed disturbances (x) to the growth equation compared with a normal variable.

Then consider environmental variability. Both stock growth and recruitment are subject to disturbances, i.e., deviations from what the estimated, deterministic models predict. The growth disturbances are not serially correlated and are lognormally distributed, after a suitable transformation.[3] Figure 4 compares the growth disturbances with a normally distributed variable with the same mean and standard deviation.

As Table 2 shows, there is a strong serial correlation in recruitment. This correlation is not due to recruitment in year *t* affecting recruitment in subsequent years, but to serial correlation

[3] The stock growth disturbance was calculated as the difference between actual and simulated stock growth (cf. Figure 1). The transformation is $x = \ln\left[(u+k)/(\mu+k)\right]$ where u is the disturbance, μ is the mean of u, and k is a constant (1500).

in the environmental disturbances that affect recruitment. Favorable conditions in the ocean apparently persist for some years, as do unfavorable ones. Having taken serial correlation in recruitment into account, we can calculate the remaining, presumably random environmental disturbance. This disturbance term is close to lognormally distributed, after a suitable transformation akin to what was done for the growth function.[4] Figure 5 shows the distribution of the disturbance term and compares it to a normally distributed variable with the same mean and standard deviation.

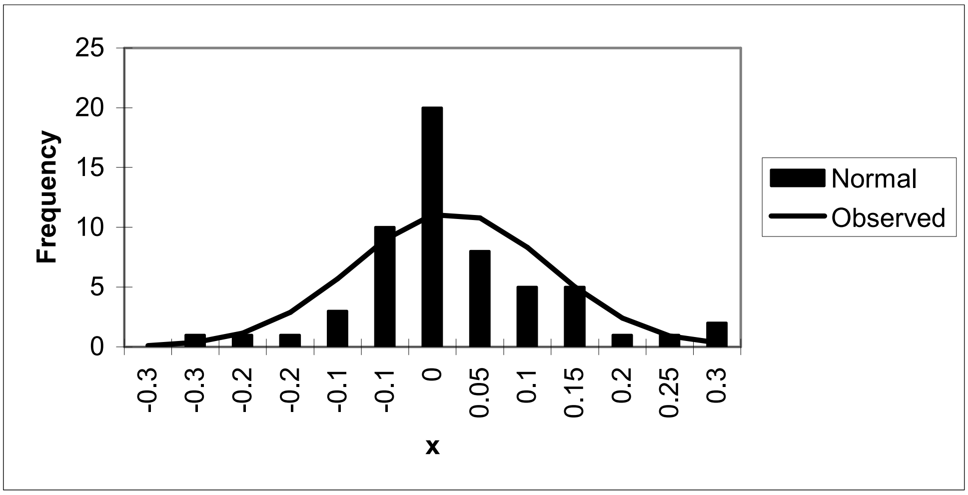

Figure 5: Distribution of the transformed disturbances (x) to a serially correlated recruitment compared with a normal variable.

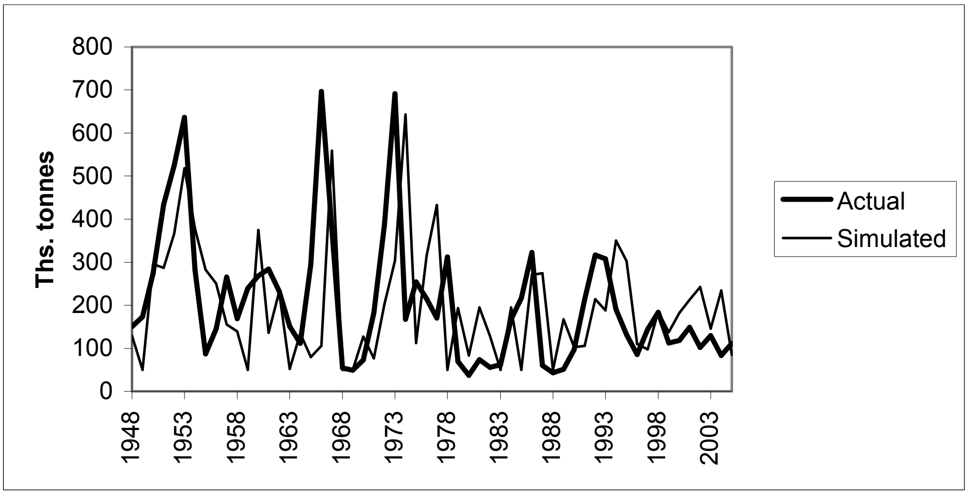

Figure 6: Actual and simulated recruitment. In the simulation, the serial correlation in Table 2 was used (two lags), and a lognormal disturbance term added for each year. Recruitment in 1946 and 1947 were used as starting values.

Using the serial correlation estimated in Table 2, it is possible to simulate recruitment over some given period for any two given starting values, using a lognormally distributed random term (see Figure 5). Needless to say, the simulated recruitment will vary greatly, depending

[4] The transformation is the same as for the growth function (see previous footnote), except for the constant, which is 1200.

on which draws of the random disturbance term come up. What is quite remarkable, however, is that it turns out to be possible to reproduce a recruitment pattern that is fairly similar to the observed one. Figure 6 shows one such pattern. It is particularly noteworthy that the peaks in the 1960s are reproduced, as are the much less marked peaks in later years. The apparent break in the recruitment pattern that seems to have occurred after 1970 thus need have nothing to do with a changed regime in the ocean, as one might be tempted to conclude, but could be produced by pure randomness. The simulated recruitment was started with the values for 1946 and 1947 and a minimum of 50 imposed; otherwise it can happen that slightly negative recruitment will be produced.

OPTIMAL UTILIZATION

As a point of reference, the optimal utilization of the stock will be discussed first. Reed (1979) established that optimal utilization of a stock implies a fixed escapement target, both under certainty and when the uncertainty about stock size is revealed before the catch quota is determined. This is not the principle on which the stock is managed and not necessarily optimal either if the price of fish depends on the quantity caught, but will be used here because it is simple and sufficient to establish what kind of response would be appropriate by one party to the management game, given that the other party does not stick to the strategy of cooperation.

The escapement target can be shown to depend on the capital costs in the industry (Hannesson, 1987, 1993), but this will not be an issue here. Then, the present value of rents (V) from the fishery in the deterministic case is

$$(7) \qquad V = p\left(X_0 - S\right) - c\left[\ln\left(X_0\right) - \ln\left(S\right)\right] + \frac{p\left(X(S) - S\right) - c\left[\ln\left(X(S)\right) - \ln\left(S\right)\right]}{r}$$

where S is the stock left after fishing ($S = X - Y$). This assumes implicitly that the optimal steady state solution should be approached as quickly as possible, as will be the case if the cost per unit of fishing effort is constant. In the first period the stock will be reduced to the permanently optimal level. The cost function pertains to the case where the cost per unit of effort is constant and the catch per unit of effort is inversely proportional to the exploited stock (for other cases, see Hannesson and Kennedy, 2005). The function $X(S)$ is given implicitly by (1).

We will also consider the case where there is no stock effect, i.e., when the catch per unit of effort is independent of the stock. In that case we can proceed as if $c = 0$ and subtract the constant unit cost from the price, p, which is assumed constant and independent of landings.

The optimal standing stock is given by the first order condition

$$(8) \qquad \left(r+1\right)\left[\frac{c}{S} - p\right] + \left(a - 2bS\right)\left[p - \frac{c}{R + aS - bS^2}\right] = 0 .$$

In the case of no costs, the optimal standing stock is independent of recruitment (R). Using the estimates in Table 1 and setting $r = 0.05$, the optimal S is 1755. With costs, the optimal S depends on recruitment. This has varied between 37 and 696 thousand tonnes in the period considered, with an average of 206. For $c = 1600$ and R equal to 50, 200 and 700 we get S

equal to 2562, 2628 and 2782. It may be noted that the natural equilibrium level of the stock is 3948, 4191, and 4861, for the three said levels of recruitment. Hence, in the absence of stock-dependent unit costs, the optimal standing stock is slightly below one half of the natural equilibrium, and slightly below two-thirds of the natural equilibrium with $c = 1600$.

Taking environmental variability into account makes it necessary to resort to dynamic programming. The Bellman equation for this problem is

$$(10) \qquad V_t = \max_{X \geq S > 0} \left[\pi(S) + \delta \mathrm{E} V_{t+1} \right]$$

where $\pi(S)$ is the rent in the current period from leaving behind the stock S after fishing (the first two terms in Equation [7]). To apply this the stock was discretized into intervals of 100 between 200 and 6200, hence ruling out extinction, and the standard normal variable, used for calculating the random environmental variables for growth and recruitment, was discretized into 21 values. Ignoring the serial correlation in recruitment, we have a time-autonomous problem and can find V by successive approximations, starting with $\mathrm{E}V_{t+1} = 0$ and, on each step, substituting $V_t(X_t)$ into $V_{t+1}(X_{t+1})$. For each given X_t and the associated optimal fishing there will be a probability distribution for obtaining each $V_{t+1}(X_{t+1})$, due to the growth function $X(S)$ and the random environmental variables. In the costless case this results in an optimal escapement of $S = 1800$ for “low” R (50), and $S = 1700$ for “high” R (700), while in the certainty case we had $S = 1755$, independently of R. For $c = 1600$ we get S =2600 for “low” R (50) and $S = 2700$ for “high” R (200 and 700). This accords with the deterministic case, where we got a higher value for S the larger the recruitment.

RESULTS OF DIFFERENT FISHING STRATEGIES

Let us now consider the present value of the fishery rent over a hundred year period, under three assumptions:

(i) Both countries follow a constant escapement strategy, close to the optimal escapement identified in the previous section;

(ii) Russia cheats on its commitment and takes x tonnes in excess of its allocated share of the total catch, except that in years when the initial stock is less than the target escapement, Russia honors its commitment not to fish at all;

(iii) Norway retaliates by fishing the y tonnes in excess of its allocation that maximizes its rents for the given level of Russian overfishing. Like Russia, it refrains from fishing if the initial stock is less than the target escapement.

The model used starts with given initial values of stock and recruitment and draws values of the random environmental variables for stock growth and recruitment with a random number generator, taking the serial correlation in recruitment into account. When evaluating the results in (i)-(iii) the same drawings of the random variables are used, as the comparison should not be blurred by differences in environmental conditions. Two cases are considered, unit cost of fish independent of the stock (the costless case), and strong dependence of the unit cost on the stock, with $c = 1600$. In the costless case the target escapement is set at 1700 and the initial stock at 2000. With $c = 1600$ the target escapement is set at 2600 and the initial stock at 3000. These escapement targets are close to the optimal escapement found above for different recruitments.

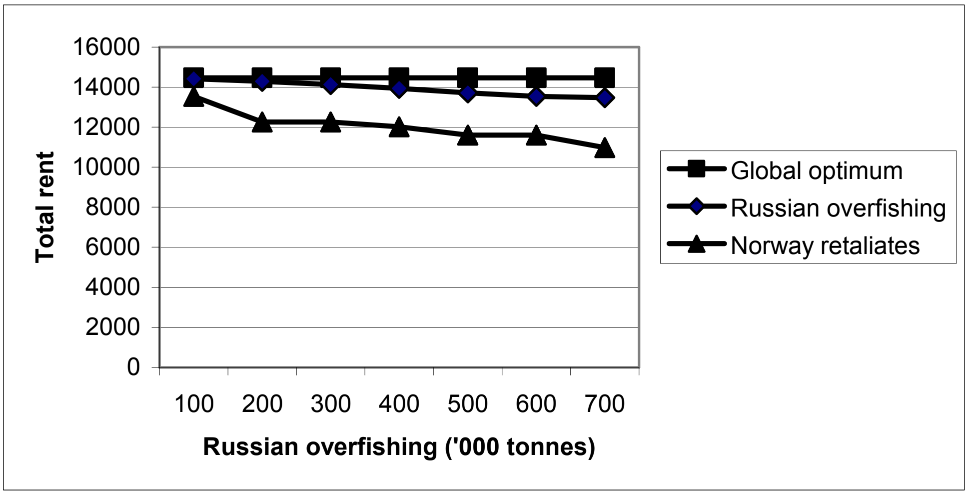

Figure 7: Total rent (present value) under three strategies. Constant unit cost of fish.

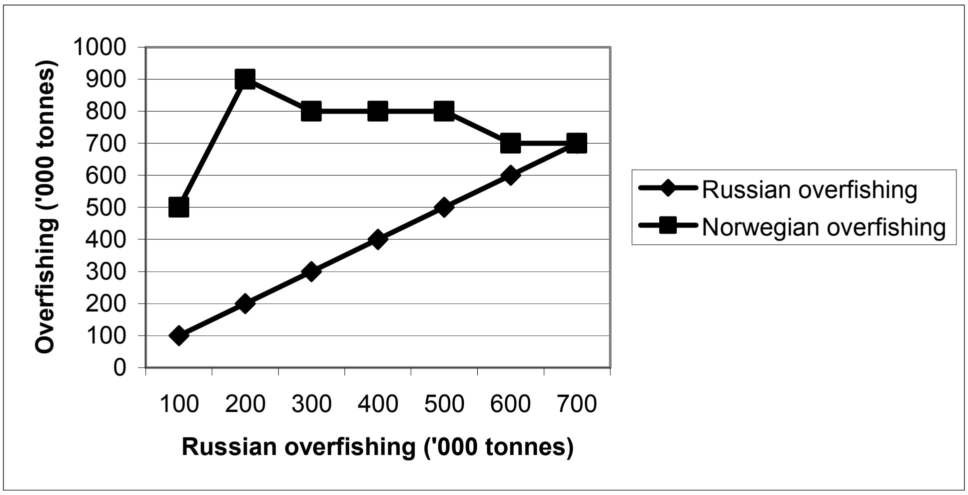

Figure 8: Best Norwegian response to Russian overfishing. Constant unit cost of fish.

The comparisons of (i)-(iii) are shown in Figures 7-16. Figure 7 compares the present values of the total rent in the fishery in the costless case. Here, overfishing by Russia alone results in a relatively moderate fall in the aggregate rent. Since the annual rent is simply proportional to the total catch, this implies that the total catch is not much affected by the Russian overfishing. If Norway retaliates by choosing its rent-maximizing level of overfishing in response, the aggregate rent falls substantially. The reason is that the rent-maximizing level of Norwegian overfishing is often higher than the Russian overfishing for any given value of the latter. Figure 8 shows the Norwegian rent-maximizing level of overfishing for different levels of Russian overfishing. The Norwegian overfishing exceeds the Russian one up to 700,000 tonnes of Russian overfishing. Hence overfishing of 700,000 tonnes by each party is thus the symmetric Nash equilibrium in this fishery. This is more than the average catch under the optimal escapement policy and results in a pulse fishing pattern; i.e., one where there are short, intensive spikes of fishing during which the stock is knocked way below the optimal escapement level, with no fishing in between allowing the stock to recover. Such fishing patterns are unlikely to be optimal if price depends on the quantity fished, but suffice to show that a one-sided adherence to a cooperative solution is unlikely to be optimal if the other party follows a different strategy.

In the case of stock-dependent unit costs of fish the decline in rents from Russian overfishing is greater (Figure 9). The reason is simple; with stock-dependent unit costs of fish the costs rise when the stock is depleted, adding to the loss of rent due to falling catches. The decline in aggregate rents is greater still if Norway retaliates by going for its rent-maximizing overfishing. The rent-maximizing level of Norwegian overfishing is smaller than the Russian overfishing for high levels of the latter (Figure 10), the reason being that the stock depletion caused by Russian overfishing will raise the cost of fishing, and Norwegian overfishing on top of that would further aggravate that problem. Here the symmetric Nash equilibrium is an overfishing of 500,000 tonnes by each party.

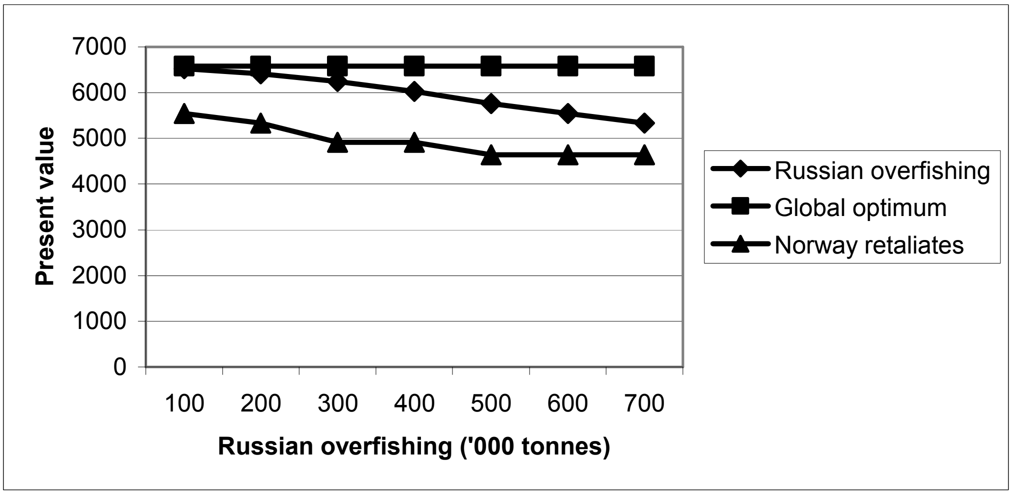

Figure 9: Total rent (present value) under three strategies. Stock-dependent unit cost of fish.

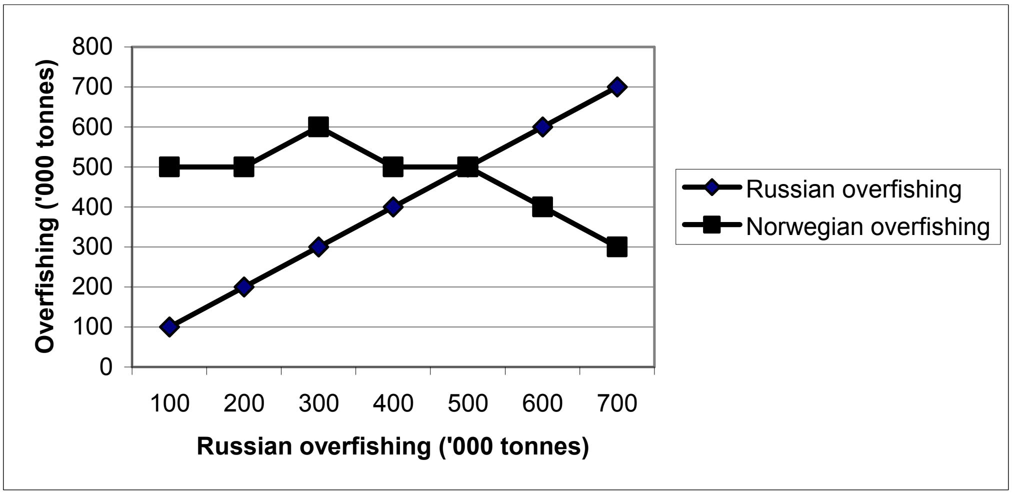

Figure 10: Best Norwegian response to Russian overfishing. Stock-dependent unit cost of fish.

Figures 11 and 12 compare Russian and Norwegian payoffs with Russian overfishing to what each of them would get if they followed the target escapement policy. Clearly Russia is much better off than in the cooperative solution if Norway does not retaliate. The payoff for Norway is in both cases severely reduced by the Russian overfishing.

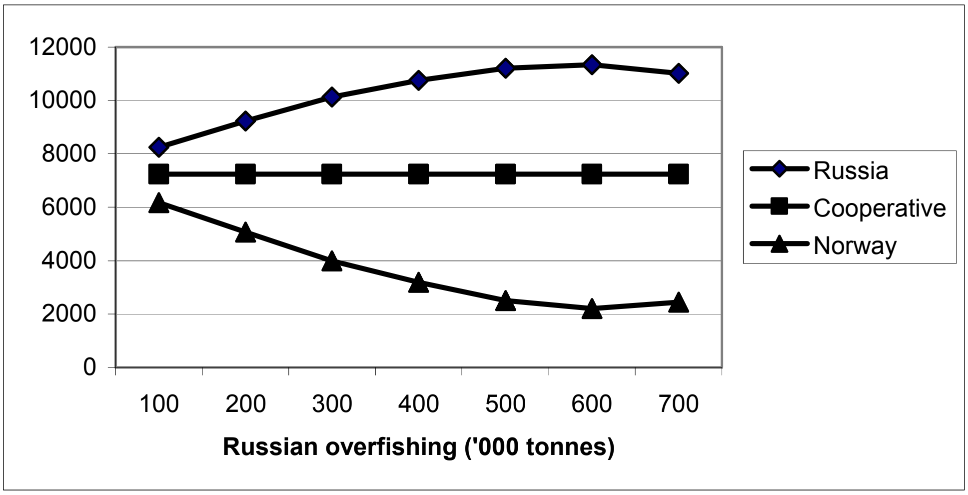

Figure 11: Payoff to Russia and Norway with Russian overfishing, compared to payoff in cooperative solution. Constant unit cost of fish.

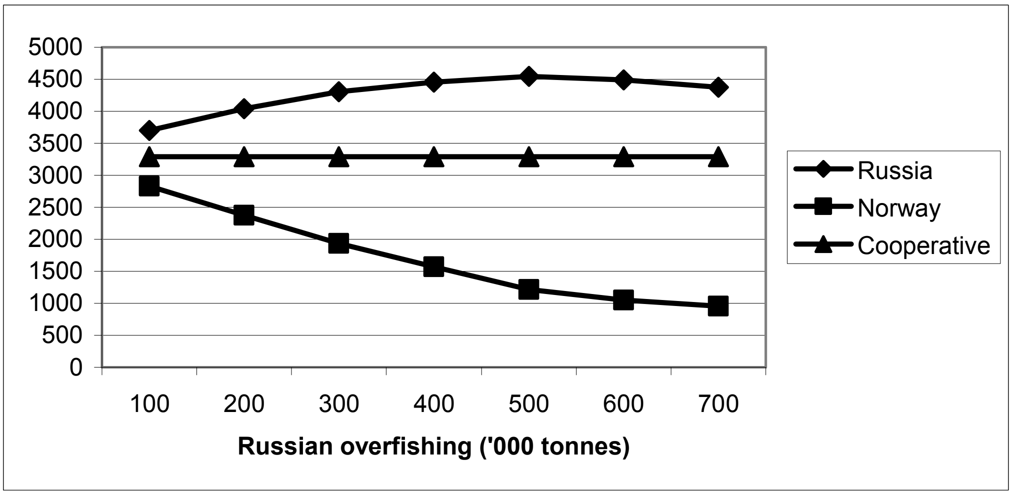

Figure 12: Payoff to Russia and Norway with Russian overfishing, compared to payoff in cooperative solution. Stock-dependent unit cost of fish.

Figures 13 and 14 show the payoffs for Norway in three cases, (i) cooperation of both parties, (ii) Norwegian compliance and Russian overfishing, and (iii) Norway responding to Russian overfishing by selecting its rent-maximizing level of overfishing. Norway is clearly much better off by retaliating than by continuing to follow the optimal escapement policy if the Russians overfish. For moderate overfishing by the Russians, Norway would actually be better off overfishing than if both parties followed the optimal solution. Furthermore, Norway's individual rent-maximizing level of overfishing is less than the Russian one for high levels of the latter (Figure 10). One conclusion to draw from this is that if one party is going to break out of the cooperative solution, it should do so on a grand scale, so as to minimize the possible retaliation by the other player. Another is that it could be too costly for the other party to punish the uncooperative player by also overfishing. The reason for why it might still be worth while for Norway to retaliate would be the economic losses inflicted on Russia, which might provide incentives for Russia to agree and adhere to the cooperative solution.

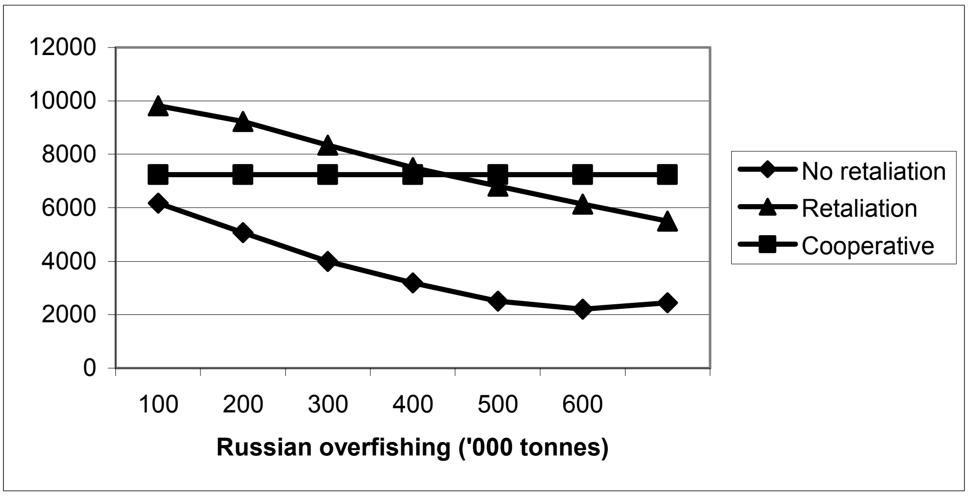

Figure 13: Payoff to Norway in cooperative solution and with Russian overfishing, with and without retaliation. Constant unit cost of fish.

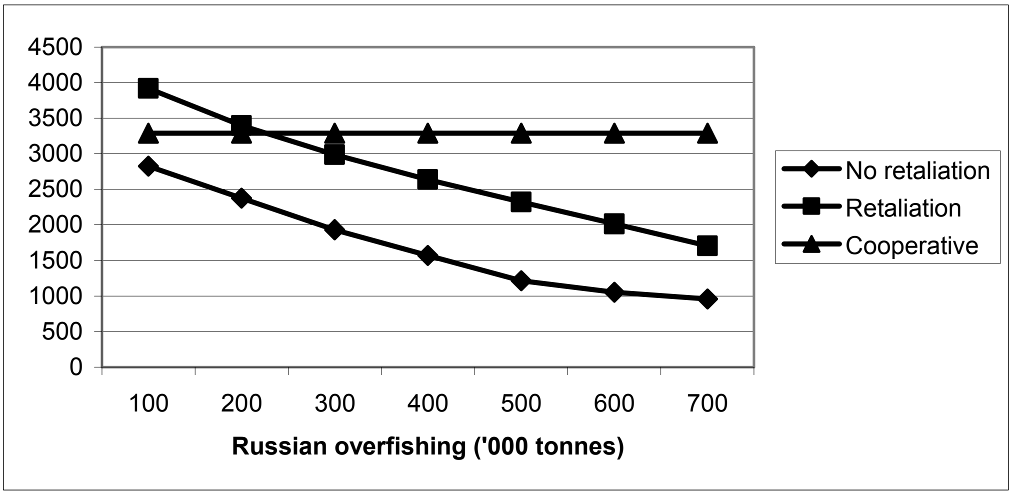

Figure 14: Payoff to Norway in cooperative solution and with Russian overfishing, with and without retaliation. Stock-dependent unit cost of fish.

Finally, Figures 15 and 16 show the payoff to Russian overfishing, given that Norway retaliates by choosing its rent-maximizing overfishing. In both cost cases substantial overfishing pays better than a small one, but overfishing is never better than the one-half share of the cooperative solution.

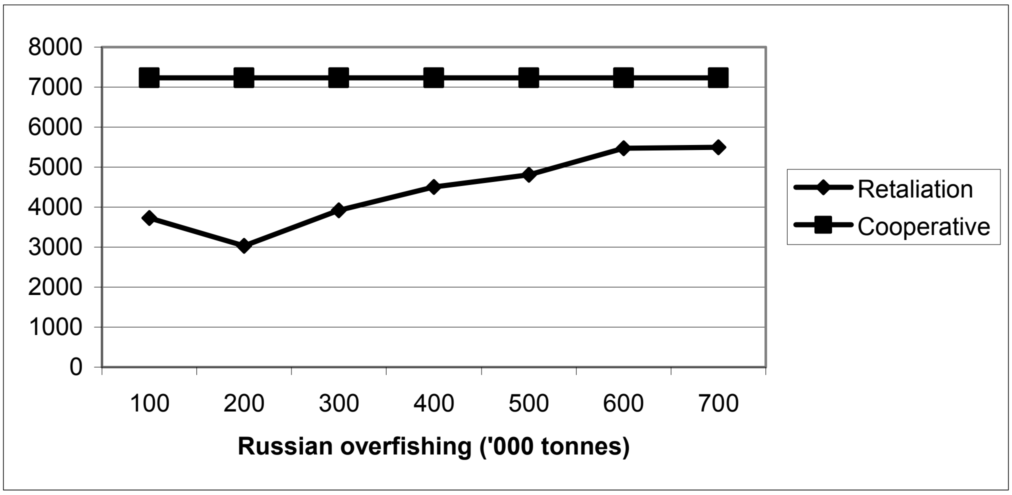

Figure 15: Russian payoff with Russian overfishing and Norwegian retaliation compared with the cooperative solution. Constant unit cost of fish.

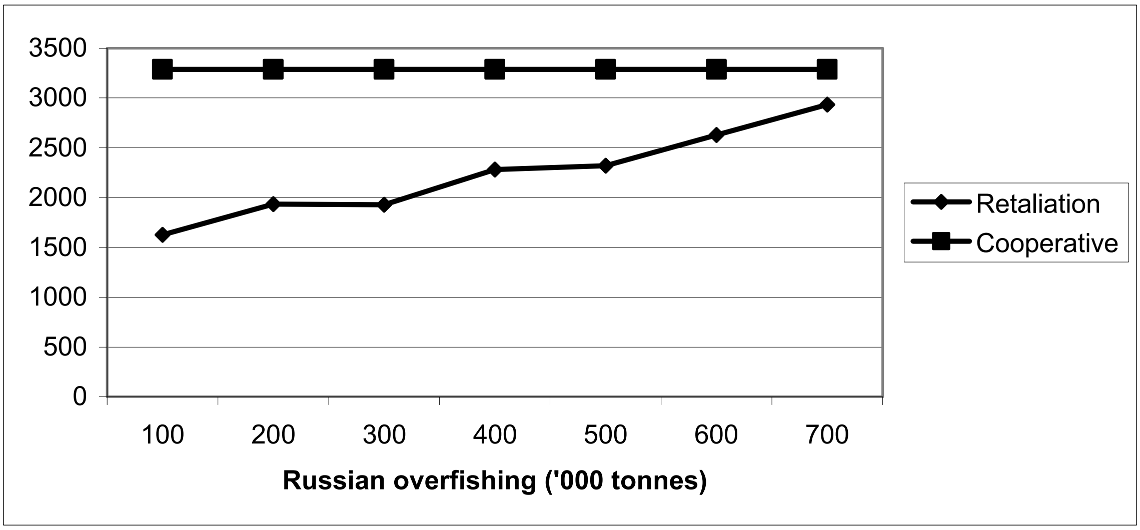

Figure 16: Russian payoff with Russian overfishing and Norwegian retaliation compared with the cooperative solution. Stock-dependent unit cost of fish.

CONCLUSION

The main loss from Russian overfishing of the Northeast Arctic cod is likely to be reduced payoff for Norway, in the form of reduced future catch quotas and higher costs from fishing from a smaller stock. Despite reducing future stock levels and quotas, Russia is likely to gain from fishing in excess of its quota, and it seems likely that Russian overfishing would have to be very large in order to have so negative overall effects as to harm Russian interests in the absence of Norwegian retaliation. It seems clear that Norway's best response would be to overfish as well, and the more so the lower the level of Russian overfishing. There are cases, however, where Norway's best reply to Russian overfishing would be only moderate overfishing, especially if the unit cost of fish depends on the stock. This would also be more likely if the costs in Norwegian fishing are higher than the costs in Russian fishing.

This specific case illustrates several general points about the exploitation of a shared resource. First, non-cooperation could result in stocks that are way below their maximum sustainable yield level and a very substantial erosion of economic rent. Second, the game could be of the "chicken" variety; if one party plays non-cooperatively the best strategy for the other party could be to retaliate only moderately. Third, non-cooperative exploitation will result in substantial gains for the player that does not cooperate, unless the other players retaliate by playing non-cooperatively as well. The implicit threat of responding to non-cooperation by a similar strategy is what ultimately sustains cooperation, and negligence to carry out such threats if some players act non-cooperatively is likely to damage the prospects of future cooperation.

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