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International Management of North Sea Herring

by

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Abstract

North Sea herring is a transboundary resource, shared by the EU and Norway. The purpose of this paper is to investigate how the harvests or total allowable catch quotas (TACs) for this species should be divided between these two countries so that both parties are satisfied. We apply a discrete-time game-theoretic model in which we show that the EU should be allocated more than half of the TAC even if the EU has higher harvesting costs. This result is due to the distribution pattern of the herring, with a larger share of herring located in the EU zone. However, we find that according to the Nash bargaining solution, the current sharing allocates too large a share to the EU.

Keywords: Fisheries, game theory, international management, North Sea herring, shared stocks

JEL codes: C70, Q22

1. The Fishery

The North Sea herring stock was severely depleted in the late 1960s and 1970s due to over-fishing under an open access regime. The stock was close to extinction in 1977, when a moratorium on fishing was introduced (Bjørndal, 1988). Severe regulations, combined with a few years with good recruitment, allowed the stock to recover, and the fishery was reopened in the early 1980s. The stock reached a peak of 3.3 mill. tonnes in 1989. It was reduced to a level of about 2 – 2.5 mill. tonnes during 1993-96. Subsequently, due to stricter regulations, it increased to an estimated level of 3.6 mill. tonnes in 2001. The safe biological limit is set at 800,000 tonnes.

North Sea autumn spawning herring (Clupea harengus L.) consists of three spawning stocks with spawning grounds east of Scotland, east of England and in the English Channel. However, the three stocks mix on the feeding grounds in the central and northern North Sea, rendering it impossible to distinguish between catches from the three stocks. It is therefore customary to treat the three stocks as one. The North Sea herring fishery takes place in the central and northern North Sea, with the main season in the months May to September. Most of the catches are used for human consumption.

One of the difficulties of implementing a management plan is the transboundary nature of the fishery. This is because North Sea herring is harvested by several European nations. The most important fishing nations are Norway, Denmark, Scotland and the Netherlands, but a number of other European nations also participate in the fishery. While purse seiners are the predominant technology in Norway, trawlers are most important in the other countries.

In view of the difficulties that have occurred in the past with regard to the management of North Sea herring, it is of great interest to study what an appropriate management policy for the resource would be. After the introduction of Extended Fisheries Jurisdiction (EFJ), North Sea herring has been considered a joint stock shared by Norway and the European Union (EU). Therefore, there are two major management decisions: first, to determine Total Allowable Catch quotas (TACs) for the sustainable management of the stock, second, to determine how the TAC should be split between the parties involved in the fishery. While the first issue was addressed by Bjørndal (1988), the second issue has not been previously addressed, neither for North Sea herring, nor for other shared stocks. In this paper, we analyse both these issues.

Currently, the split between the two parties is such that Norway receives a 29% share of the TAC, and the EU 71%. The sharing is largely based on the geographical distribution of the stock between the Exclusive Economic Zones of Norway and the EU.

In the model we use a game-theoretic framework to analyse the international management of herring. In the past there have been many mainly theoretically oriented papers on transboundary fisheries management starting from the seminal work by Munro (1979) (see Lindroos and Kaitala (2001) for a review). However, only recently have we seen empirical applications of these models such as Sumaila (1997), Armstrong (1999), Brasão et al. (2000) and Pintasslgo and Duarte (2000).

The paper is structured as follows. In section 2, the model is outlined. In section 3, sole owner, cooperative and non-cooperative management are analysed. A summary is provided in section 4.

2. The Model

We assume there are two players in this fishery, Norway and the EU. We describe the fishery with a Cobb-Douglas production (harvest) function (see Bjørndal and Conrad 1987):

$$(1) \qquad h = qE^{\beta}S^{\alpha}$$

where h is harvest quantity in tonnes, q the catchability coefficient, E is fishing effort, and S stock size, measured in tonnes. The term α is the stock output elasticity and β is the effort elasticity.

As mentioned above, North Sea herring is a joint stock shared by Norway and the EU. Each nation receives a share of the TAC, which is based on the distribution of the stock between the two EEZs. To capture this fact, we will introduce a distribution parameter, F, which represents the fraction of the stock available to Norway. This implies that (1 – F) is the fraction of the stock available to the EU. Then the harvest functions become:

(2a) $h_1 = q_1 E_1^{\beta} F S^{\alpha}$ for Norway and

(2b) $h_2 = q_2 E_2^{\beta} (1 - F) S^{\alpha}$ for the EU.

With this representation, it is as if Norway exploits a stock equal to FS, while the EU exploits a stock given by (1 – F)S. This is a novel way of modelling exploitation of a shared stock not previously seen in the literature. Terms q_1 and q_2 are the catchability coefficients of the two players. These may be different, as different technologies are used.

Munro (1979) modelled a two-country game where one of the parameters was the share of total harvests. In the current model, however, we are interested in how the negotiations are affected when the two countries have different shares in the stock. The Munro model and the current model are technically very similar with the exception that the current model considers non-linear production functions for the countries. Furthermore, Munro (1979) treats the share of total harvest as a control variable. In our model F can not be a control variable since it measures the physical availability of the fish stock to the two countries.

Natural growth is given by the logistic function for the common resource:

(3) $F(S) = rS(1 - \frac{S}{K})$,

where r is the intrinsic growth rate and K the carrying capacity of the environment.

Our model is formulated in discrete-time with the following population dynamics:

$$(4) \qquad S(t+1) = S(t) + rS(t)\left[1 - \frac{S(t)}{K}\right] - q_1 E_1^{\beta} F S(t)^{\alpha} - q_2 E_2^{\beta} (1-F) S(t)^{\alpha}$$

Thus, the change in biomass S is given by the difference between growth and harvests.

The objective of each of the countries is to maximise the net present value of net revenues from the fishery:

$$\max \quad \sum_{t=1}^{T} P_i(t) = \sum_{t=1}^{T} \left[\frac{ph_i - c_i E_i}{(1+\delta)^{t-1}} \right]$$

s.t. equation (1)

$$E_i(t) = E_i \;\; for \;\; P_i(t) \geq 0$$

$$E_i(t) \leq E_i^{\max}$$

If $P_i(t) < 0$, then $E_i(t) = 0.$

Here p is the price per kilogram, c_1 and c_2 are the unit costs of harvesting, T is the planning horizon and r is the discount rate. Price is assumed to be the same for both countries. The unit costs of harvesting, however, are different for Norway and the

EU. The reason is that the two countries employ different technologies. We use the number of vessels as a measure of fishing effort. The remaining conditions imply a constant fleet size for periods of non-negative profits and a capacity constraint that gives an upper level of the fleet size. Further, we have an exit condition, which says that if a country earns negative profits then it will not participate in the fishery during that year.

Our numerical results for the management of North Seas Herring in the sole owner, cooperative and two-player cases use the following parameters:

Simulation period: T = 50 years;

p = 1,920 NOK per tonne of herring;

c_1 = 1.124 million NOK;

c_2 = 1.124 – 1.924 million NOK;

r = 0.53;

K = 5.27 million tonnes;

S(1) = 3.591 million tonnes;

$q = q_1 = q_2$ = 0.06152;

α = 0.562;

β = 1.356;

F = 0.29;

$E_i^{\max}$ = 1000 vessels;

δ = 0 or 0.05;

The price represents the average price to fisherman per tonne of North Sea herring in 2000 (source: Norwegian Fishermen's Sales Organisation for Pelagic Fish). Term c_1 is the cost of operating a Norwegian purse seiner for one season, again based on 2000 figures (source: Directorate of Fisheries, Norway). Only variable costs are considered, as purse seiners participate in a number of seasonal fisheries. Term c_2 is the cost of operating an EU-vessel for one season. As cost data are not available for EU-vessels, it is assumed that their costs are at least as high as the Norwegian, which is appropriate, according to industry sources.

Parameters for the intrinsic growth rate r and the carrying capacity of the environment K have been estimated based on biological data for the period 1981-2000 from the International Council for the Exploration of the Sea.

Production function parameters (α, β and q) are taken from Bjørndal and Conrad (1987). The reason these parameters have not been re-estimated is that while Bjørndal and Conrad used data from a period characterised by open access, the fishery in recent years has been characterised by individual vessel quotas. For this reason, re-estimated parameters would be biased. It is recognised that this assumption may underestimate efficiency in the fleet.

A stock output elasticity (β) less than one is commonly found for fisheries on schooling stocks such as herring. The implication is that as stock size is reduced, catch per unit effort is reduced less, relatively. This is the reason why open access harvesting of schooling fish stocks leads to overexploitation.

Term S(1), the initial value of stock for simulations, is from 2001 (see Bjørndal 1988 for comparison).

3. Analysis

The Cooperative and Sole Owner Cases

First we consider the sole owner case and cooperative management. In the sole owner case, Norway is the only harvester, as it has the lowest harvesting costs.

Table 1 shows the results, comparing the sole owner case and cooperation where vessels (catches) are distributed using the same percentages as the distribution of the stock (29 %, 71 %). Table 1a is for a zero discount rate and table 1b for discount rate of 5 %. The optimal sole owner effort is calculated to be $E^* = 345$ or $E^* = 360$ depending on the discount rate. The cooperative optimal fleet sizes are slightly higher but stock level is higher due to the shape of the biological growth function. Total profits in the sole owner case are 19.39 (5% discount rate) and 48.84 billion NOK (zero discount rate). With cooperative management and EU-costs similar to Norwegian, total profits are 18.13 and 45.69 billion NOK. The reduction is due to increased effort in the cooperative case. Tables 1a and 1b reveal that in the zero discount rate case optimal fleet size is smaller and consequently stock size larger than in the case of positive discount rate.

Table 1a: Cooperation and sole ownership of the North Sea herring fishery (δ = 0 %)

	Sole owner	Cooperative (EU costs: 1.12, 1.52, 1.92)		
Steady state (after 50 years) stock level (mill. Tonnes)	2.69	2.72	2.80	2.85
Steady state catch (mill.tonnes)	0.70	0.70	0.70	0.69
Total effort (vessels) and per country (Norway, EU)	345 (345, 0)	400 (120, 280)	395 (118, 277)	390 (117, 273)
Profits (Norway, EU)	48.84, 0	9.09, 36.60	9.10, 30.94	9.09, 25.38
Total profits (billion NOK)	48.84	45.69	40.04	34.47
Number of active years (Norway, EU)	(50, 0)	(50, 50)	(50, 50)	(50, 50)

Table 1b: Cooperation and sole ownership of the North Sea herring fishery (δ = 5 %)

	Sole owner	Cooperative (EU costs: 1.12, 1.52, 1.92)		
Steady state (after 50 years) stock level (mill. Tonnes)	2.39	2.48	2.57	2.63
Steady state catch (mill.tonnes)	0.69	0.70	0.70	0.70
Total effort (vessels) and per country (Norway, EU)	360 (360, 0)	415 (124, 291)	410 (123, 287)	405 (121, 284)
Profits (Norway, EU)	19.39, 0	3.61, 14.53	3.61, 12.28	3.61, 10.07
Total profits (billion NOK)	19.39	18.13	15.89	13.68
Number of active years (Norway, EU)	(50, 0)	(50, 50)	(50, 50)	(50, 50)

Figures 1 and 2 illustrate the dynamics of stock size and total harvests, respectively, for EU-costs of 1.52 mill. NOK per boat per season. The initial stock is very high, so there is first a period of "mining" the stock. The stock is gradually reduced and reaches the steady state level of 2.57 mill. tonnes in about 2020. Annual harvest is also gradually reduced over time until it reaches the steady state of 0.7 mill. tonnes annually.

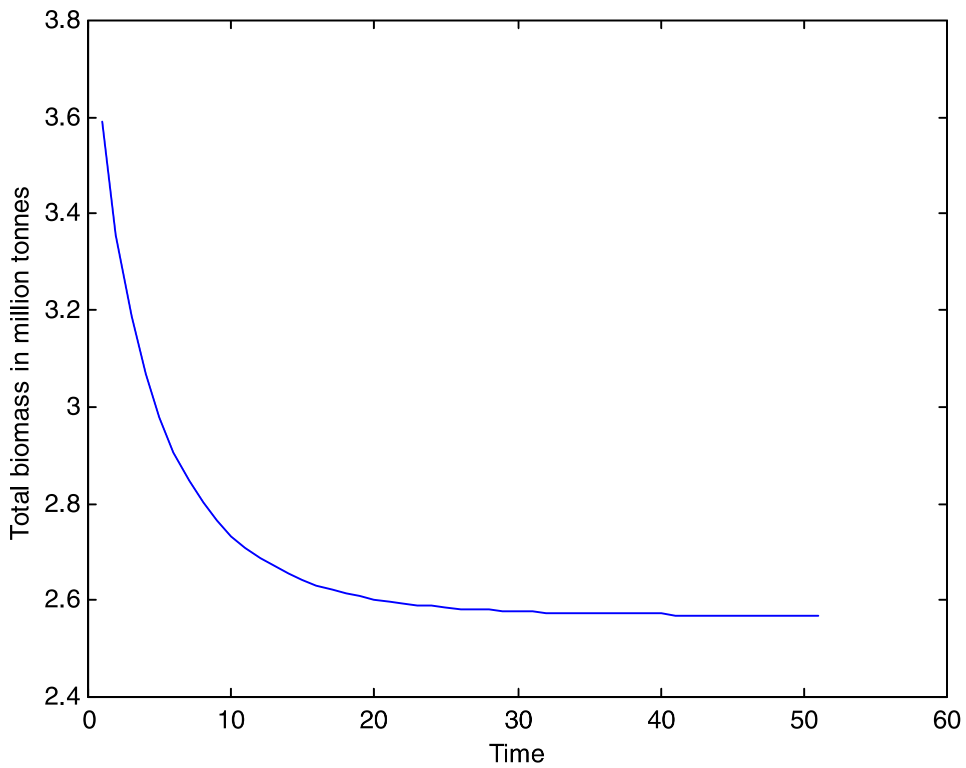

Figure 1: Total biomass of North Sea herring in cooperative case (EU costs 1.52, δ = 5 %)

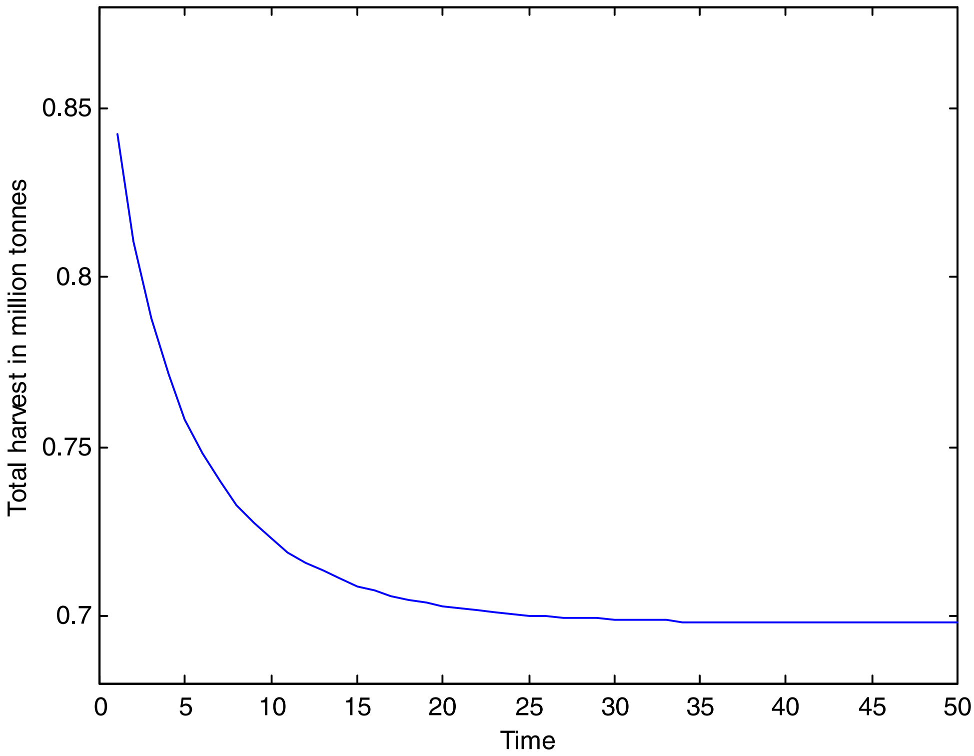

Figure 2: Total harvest of North Sea herring in cooperative case (EU costs 1.52, δ = 5

The Non-cooperative Equilibrium

The non-cooperative equilibrium is found to be very sensitive to changes in harvesting costs (Table 2). In the high EU-cost scenario, the stock is actually driven to extinction for a discount rate of 5 %. When the EU has sufficiently low costs it affords to be active all through the simulation period.

The non-cooperative equilibrium is also related to the value of F. The higher share of the resource gives the EU a competitive advantage since it has access to a larger share of the total stock. Therefore, the EU can be in a better position compared to Norway even with higher unit costs of harvesting. This cost effect will be reduced whenever a country has access to more than 50 % of the stock because a unit of effort is more productive (see equation 2). The country with a large share of the fishery can harvest the same amount of fish using less effort than the small share country. This means that the cost per fish harvested may be less for the country with a higher unit cost of effort. The value of F and the cost difference together determine which effect is dominant in the equilibrium – the (unit) cost (of effort) effect or the distribution effect.

Table 2a: Non-cooperative equilibria (stable) of the North Sea herring fishery (δ = 0 %)

	Non-cooperative (costs of EU 1.12, 1.52, 1.92)		
Steady state stock level (mill. tonnes)	0.92	0.92	1.03
Steady state catch (mill. Tonnes)	0.39	0.39	0.44
Total effort (vessels) and per country (Norway, EU)	1450 (1000, 450)	1450 (1000, 450)	1650 (1000, 650)
Profits (Norway, EU)	1.35, 16.19	1.35, 7.19	1.01, 5.92
Total profits (billion NOK)	17.54	8.54	6.93
Number of active years (Norway, EU)	5, 50	5, 50	2, 30

Table 2b: Non-cooperative equilibria (stable) of the North Sea herring fishery (δ = 5 %)

	Non-cooperative (costs of EU 1.12, 1.52, 1.92)		
Steady state stock level (mill. tonnes)	0.92	0.44	0.38
Steady state catch (mill. Tonnes)	0.39	0.14	0.11
Total effort (vessels) and per country (Norway, EU)	1450 (1000, 450)	1800 (1000, 800)	2000 (1000,1000)
Profits (Norway, EU)	1.30, 7.25	0.81, 4.15	0.81, 3.91
Total profits (billion NOK)	8.55	4.96	4.72
Number of active years (Norway, EU)	5, 50	1, 17	1, 10

Note that total effort refers to effort level that is applied if fishing is profitable, otherwise effort is zero. This explains why Norway makes small profits even if it has 1000 vessels in the first case of non-cooperation. The last row of the table gives the number of active harvesting periods. This means that Norway employs its 1000 vessels only during 5 periods in the low EU-cost scenario and even less so for the higher cost scenarios. The steady state values are average values of the last 10 years. The stock and harvests can be higher or lower for some years. Further, as we see form tables 2a and 2b, a lower discount rate tends to decrease fishing effort in the asymmetric cost cases.

Figure 3 shows the population dynamics in the medium cost equilibrium where stock size is rapidly reduced, and then varies between 0.4 – 1 mill. tonnes. The associated pattern of pulse fishing is shown in Figure 4. We see in figure 3 that the stock level most of the time is below the safe minimum biological level (0.8 mill. tonnes). This means that a small negative natural variation could drive the stock down to a very low level with a possibly long period of recovery. On the other hand if the discount rate is zero the stock level is on average above the safe biological level, and only occasionally below this level.

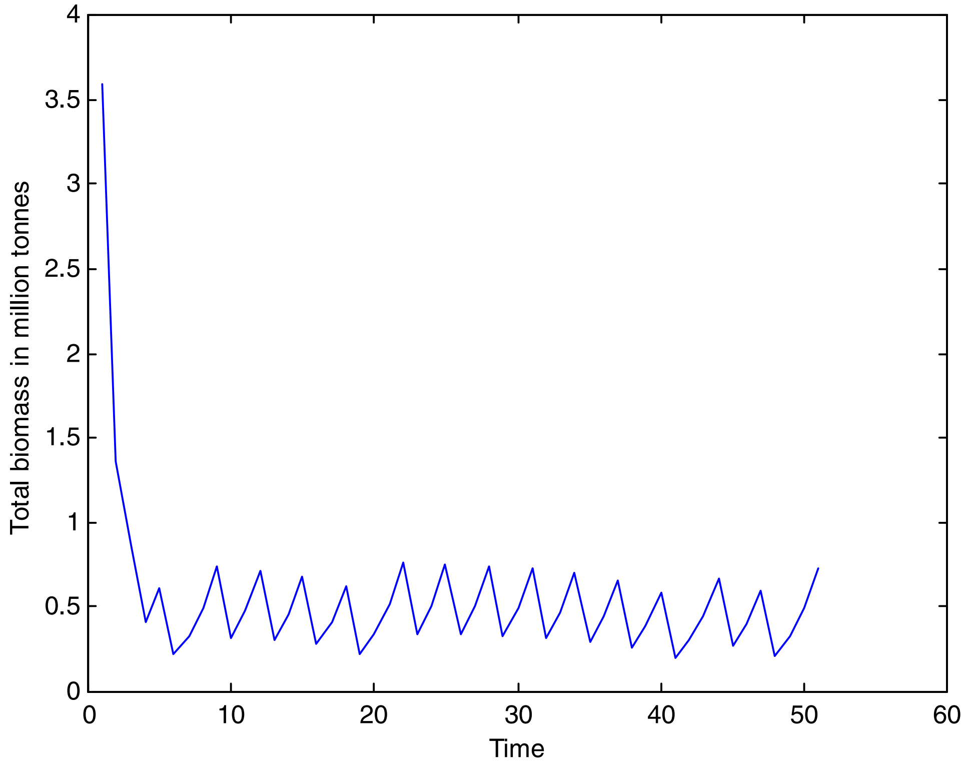

Figure 3: Total biomass of North Sea herring in non-cooperative equilibrium (EU costs 1.52, δ = 5 %)

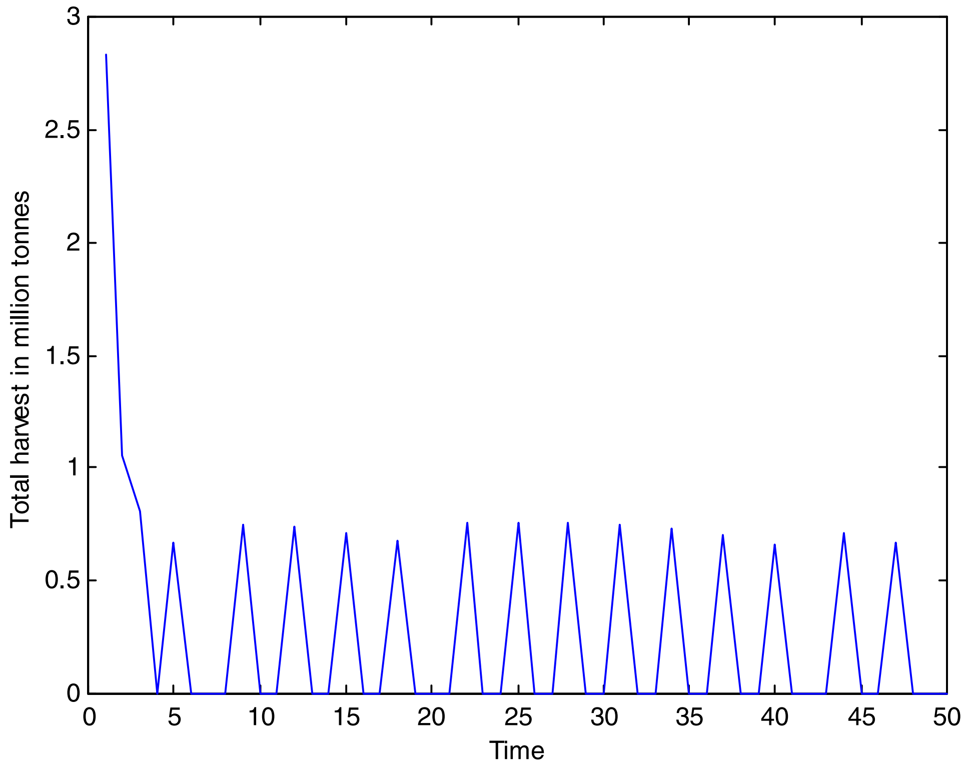

Figure 4: Total harvest of North Sea herring in non-cooperative equilibrium (EU costs 1.52, δ = 5 %)

Non-cooperation is very destructive in a biological sense. If the EU has a cost disadvantage, it does not find it optimal to reduce its fleet at all but rather change the behaviour to pulse fishing where the stock is depleted whenever it is profitable. From tables 2a and 2b we see that in the high and medium cost equilibria there are notable biological differences between the zero discount rate cases and the 0.05 % discount rate cases. The zero discount rate case produces over twice as high average stock level.

How should the fishery be shared?

Having calculated the cooperative cases and non-cooperative equilibria we are faced with the final problem of sharing the cooperative benefits in some reasonable way. A common solution is to use the Nash bargaining solution that gives an equal share of the cooperative benefits to each country (see Kaitala and Munro 1997).

Looking at Tables 1 and 2 above immediately reveals that the 29-71 % share of vessels favours the EU in the sense that it receives more than half of the cooperative benefits. For example, the high cost case of tables 1b and 2b yields 8.96 (13.68 – 4.72) cooperative benefits of which 69 % (6.16 = 10.07 – 3.91) are allocated to the EU.

Let us next calculate such a share that satisfies the equal sharing requirement (Tables 3a and 3b). We see that the management rule that gives 29 % of the total TAC to Norway is accurate in none of the cases. The highest shares should be given in the medium cost case (37 % – 39 %). According to table 3 Norway should be allocated at least 33 % of the total harvest. Thus, the actual management scheme is clearly violating the equal sharing rule. Note that the optimal number of vessels changes slightly here since the shares are also changing.

Table 3a: Sharing of cooperative benefits of the North Sea herring fishery (δ = 0 %)

	Sharing of benefits (costs of EU 1.12, 1.52, 1.92)		
Number of vessels	410	405	400
Norwegian share of vessels	39 %	42 %	39 %
Norwegian share of harvests	35 %	39 %	35 %

Table 3b: Sharing of cooperative benefits of the North Sea herring fishery (δ = 5 %)

	Sharing of benefits (costs of EU 1.12, 1.52, 1.92)		
Number of vessels	425	420	405
Norwegian share of vessels	39 %	40 %	37 %
Norwegian share of harvests	35 %	37 %	33 %

4. Discussion and Conclusions

We have studied how the harvests or TACs should be divided between the EU and Norway in the North Sea Herring fishery so that both parties are satisfied. We have shown that the EU should be allocated more than half of the TAC even if the EU has higher harvesting costs. This result is due to the distribution pattern of the herring.

Since most of the herring are located in the EU zone it is also natural to allocate a higher share of the TAC to the EU fleet. However, we find that according to the Nash bargaining solution (equal sharing of cooperative benefits), the current system allocates too large a share to the EU. Therefore, the current system demands modifications that would allocate a larger share of the TAC to Norway.

Munro (1979) reported that it is easy to find solutions that will satisfy both countries when there are differences in the discount rates or harvesting costs. Our results extend Munro's results to the case of a non-linear production function (and different harvesting costs). With the present specifications we found a single equilibrium for our shared stock game between the EU and Norway.

The model applied here would be easily applicable to other shared fisheries. Models previously used have neglected the strategic effect of geographical distribution of the fish stocks.

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