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Supply Functions for North Sea Herring

by

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Abstract

A discrete time bioeconomic model is developed and used to derive supply curves for the open access and the optimally managed fisheries. Supply curves are estimated based on data for the North Sea herring fishery. Different regulatory regimes in the fishery for the past two decades, both actual and theoretical, are evaluated with respect to effects on supply, stock level and fishing effort. The results indicate that different regulations can have a substantial impact on the supply of North Sea herring. It is argued that the annual equilibrium supply can vary from zero in case the stock is driven to extinction under open access, to a sustainable annual yield of 690-700 thousand tonnes.

1. Introduction

Market analysis is based on supply and demand. While demand functions and market structure receive substantial attention in the fisheries economic literature, very little attention is given to the supply side in fisheries. The backward-bending open access supply curve was derived in the seminal paper by Copes (1970). With the advent of optimal control theory, Clark (1990) derived the equilibrium supply curve for an optimally managed fishery. However, the literature contains few, if any, empirical studies of fisheries supply curves. Bjørndal (1987) estimated a harvest supply function, but the purpose of his study was to use duality to retrieve the characteristics of the underlying production technology, and the supply function per se was not derived.

The purpose of this paper is to derive and estimate supply functions for the North Sea herring fishery. A bioeconomic model will be developed and used to derive supply curves for the open access regime and the optimally managed fishery. These supply curves will then be empirically estimated based on data for the fishery. Thus, the paper will represent an empirical application of fisheries supply curves under different regulatory regimes.

In the next section a bioeconomic model for the fishery is developed, and equilibrium supply curves are derived. The derived supply curves will be estimated in Section 3. Section 4 contains an analysis of different regulatory regimes in the North Sea herring fishery for the past two decades. The paper is summarised in the final section.

2. The Bioeconomic Model

The North Sea autumn spawning herring (Clupea harengus) is a pelagic stock that lives on plankton. The stock consists of three spawning stocks with different spawning grounds: the northern, central and southern North Sea herring.

Herring of the central and northern populations spawn in August and September in the western North Sea. After spawning the herring migrate eastwards to spend the winter in the Norwegian Trench. In spring the fish migrate north along the Norwegian Trench and then west towards Shetland. In May-June the feeding starts in the northern part of the North Sea. The southern population spawn in December and January in the eastern English Channel. After spending the winter in the southern part of the North Sea, the herring migrate directly to the feeding grounds in the central and northern North Sea. It is normal to treat the three stocks as one, because they mix on the feeding grounds rendering it impossible to distinguish between catches from the different stocks. Primarily the herring fishery takes place in the central and northern North Sea during the months May to September.

The North Sea herring stock was severely depleted in the 1960s and 1970s due to overfishing under an open access regime combined with the development of very effective fish finding technology (Bjørndal, 1988). In 1977 the fishery was closed to allow the stock to recover. After the moratorium was lifted, regulations have been in effect. However, in the mid-1990s the stock once again was outside safe biological limits, and in 1996 the total quota was reduced to save the stock from collapse. To rebuild the stock, the quotas have been relatively small after 1996. The latest stock estimates show that the stock has been rebuilt above the level that guarantees good recruitment (ICES, 2002a).

After the introduction of extended fisheries jurisdiction (EFJ), the North Sea herring has been considered a common resource between Norway and the European Union. Management decisions are therefore agreed upon by Norway and the EU. In December 1997 the parties agreed on a management scheme for the stock, the EU-Norway agreement, specifying objectives for the stock and how to set catch quotas[1]. This agreement has been in force since 1 January 1998. According to the EU-Norway agreement, the total quota for the directed fishery shall be allocated between the two parties with 29% to Norway and 71% to the European Union. In addition the European Union gets the entire by-catch quota.

[1] Source: Anon., 2001.

Changes in the biomass of a fish stock over time come from recruitment, natural growth, natural mortality and harvesting (Munro and Scott, 1985). This can be explained by the following equation:

(1) $$X_{t+1} - X_t = F(X_t) - H(\cdot),$$

where X_t is the total biomass at the beginning of period t, $F(X_t)$ is the natural growth of the biomass in period t and H is the total catch in period t. The natural growth of the biomass will be explained by the discrete-time analogue of the logistic growth function:

(2) $$F(X_t) = rX_t\left(1 - \frac{X_t}{L}\right),$$

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

The harvest in period t will be given by the following Cobb-Douglas production function:

(3) $$Y_t = H(K_t, X_t) = aK_t^b X_t^g,$$

where K_t is fishing effort in period t. According to Bjørndal and Conrad (1987), search for schools is of predominant importance in a fishery on a schooling species like herring. Thus, in such fisheries the number of participating vessels may be an appropriate measure of effort, an assumption that will be made also in this article.

The standard Schaefer production function is a special case of equation (3), where b = g = 1. The schooling behaviour of the herring has permitted the development of very effective means of harvesting. With modern fish finding equipment harvesting can be viable even at very low stock levels. For this reason we will expect $0 \leq g < 1$ for herring. The Cobb-Douglas production function will describe a “pure” schooling fishery when g = 0.

We assume the cost per unit of effort to be constant. Under this assumption we can write the cost function as:

(4) $$C(X_t, Y_t) = c \cdot K_t = c \cdot \left(\frac{Y_t}{aX_t^g} \right)^{\frac{1}{b}},$$

where c is the variable cost per vessel per fishing season. The variable cost will not include costs associated with the crew, because crew remunerations represents a constant share of the vessel's revenue. We will therefore adjust the income by a factor that represents the boat owner's share. This leaves us with the boat owner's share of both prices and variable costs.

We define industry profit as:

(5) $$\pi_t = pH(X_t, Y_t) - cK_t = pH(X_t, Y_t) - C(X_t, Y_t),$$

where p is unit price of harvest. The industry profit equals the resource rent from the fish stock.

Equilibrium Supply

We will now derive the equilibrium supply curves for the open access fishery and for the optimally managed fishery. Copes (1970) first described the backward-bending open access supply curve, while Clark (1990) derived the supply curve for the optimally managed fishery.

i. <u>The open access fishery</u>

The equilibrium in an open access fishery is known as the bionomic equilibrium (Gordon, 1954). The conditions for the bionomic equilibrium are:

$$X_{t+1} - X_t = F(X_t) - aK_t^b X_t^g = 0$$

(6) $$\Rightarrow Y_t = aK_t^b X_t^g = F(X_t)$$

and

$$\pi_t = p \cdot aK_t^b X_t^g - cK_t = 0$$

(7) $$\Rightarrow X_{\infty} = \left(\frac{c}{paK^{(b-1)}} \right)^{\frac{1}{g}}$$

If the price changes, the profit may also change. This will lead to an adjustment in fishing effort. Because of this, the following additional condition must be satisfied:

$$\pi = pY - cK = 0$$

(8) $$\Rightarrow K_{\infty} = \frac{pY}{c}$$

Hence we can express the sustained yield, Y_{∞}, in terms of price, p, and effort, K:

(9) $$Y_{\infty} = r \cdot \left(\frac{c}{paK_{\infty}^{(b-1)}} \right)^{\frac{1}{g}} \cdot \left[1 - \frac{1}{L} \cdot \left(\frac{c}{paK_{\infty}^{(b-1)}} \right)^{\frac{1}{g}} \right]$$

The equilibrium supply is given by equation (8) and (9). While it is not possible to solve for explicit expressions for Y_{∞} and K_{∞} unless b = g = 1, it is possible to solve for Y_{∞} and K_{∞} numerically.

A pure schooling fishery is a special case of the Cobb-Douglas harvest function with a stock – output elasticity of zero. In this case the cost of harvesting is independent of the stock level. Thus, depending on the price-cost relationship, the fishermen will either increase the fishing effort until the stock is depleted, or they will not harvest at all. Either way the equilibrium supply would be zero. With b = 1 and g = 0, the stock would be depleted if $p > \frac{c}{a}$ (Bjørndal, 1988).

ii. The optimally managed fishery

We assume that a sole owner, whose objective is to maximise the present value of profits from the fishery, manages the fish stock. The present value of profits is as follows:

(10) $$J(X_t, Y_t) = \sum_{t=0}^{\infty}\left[\left(\frac{1}{1+\rho}\right)^t\left(pY_t - c\left(\frac{Y_t}{aX_t^g}\right)^{\frac{1}{b}}\right)\right],$$

where ρ is the social rate of discount. The problem is to maximise the present value of profits subject to equation (1). This is an optimal control problem, where X_t is the state variable and Y_t is the control variable. The current value Hamiltonian of this problem is:

(11) $$\tilde{H}(X_t, Y_t, \mu_{t+1}) = pY_t - c\left(\frac{Y_t}{aX_t^g}\right)^{\frac{1}{b}} + \frac{1}{1+\rho}\cdot\mu_{t+1}(F(X_t) - Y_t),$$

where μ is the co-state variable for the dynamic restriction. μ_{t+1} can be viewed as the shadow price of the resource from the perspective of period (t + 1). It is not possible to solve this problem for an explicit expression for the equilibrium yield, Y^*. But by solving the problem we can derive the following explicit expression for the price, p:[2]

(12) $$p = \frac{c}{bY}\left(\frac{Y}{aX^g}\right)^{\frac{1}{b}} + \frac{\frac{cg}{bX}\left(\frac{Y}{aX^g}\right)^{\frac{1}{b}}}{\rho - r + \frac{2rX}{L}}$$

In addition to (12), the following condition must hold in equilibrium:

(13) $$Y = F(X) = rX\left(1 - \frac{X}{L}\right)$$

Using equations (12) and (13), we can find optimal equilibrium combinations of price and yield. Clark (1990) refers to the resulting supply curve as the discounted supply curve.

We will also find the equilibrium solution for a pure schooling fishery (g = 0). Using the first order conditions for the optimal control problem, we find that the optimum is given by:

(14) $$F'(X) = \rho$$

[2] The problem is solved through an application of the Maximum Principle.

In addition to equation (14), we know that no fishermen will harvest the stock if the profit is negative. Thus, the equilibrium supply in a pure schooling fishery is given by:

(15) $$Y^* = \frac{L}{4r}\left(r^2 - \rho^2\right), \text{ if } p \geq \frac{c}{Y^*}\left(\frac{Y^*}{a}\right)^{\frac{1}{b}}$$

or $Y^* = 0$, otherwise.

From equation (15) we can see that in a pure schooling fishery the supply is independent of price and costs, as long as the price-cost ratio is above a certain level.

We now turn to the estimation of supply curves.

3. Empirical Analysis

The estimating equation for the growth function in equation (2) is:

(16) $$\left(X_{t+1} - X_t\right) + Y_t = rX_t - \frac{r}{L}X_t^2 = \beta_1 X_t + \beta_2 X_t^2 + \text{ut},$$

where $\beta_1 = r$ in (2) and $\beta_2 = \left(-\frac{r}{L}\right)$. Consequently, the carrying capacity can be expressed as $\frac{\beta_1}{-\beta_2}$. The left hand side of equation (16) represents the natural growth of the stock at time t, given by the sum of stock change and harvest during the period. The right hand side is the logistic growth function. Equation (16) is estimated using ordinary least squares based on ICES-data for annual total biomass and landings for the period 1981 - 2001[3] with results presented in Table 1. For details on the estimations, see Nøstbakken (2002).

[3] Source: Herring Assessment Working Group, ICES 2002a.

Table 1: Estimated growth function for North Sea herring. t-statistics in parentheses.

$\beta_1 = r$	0.526	(4.40)
$\beta_2 = -\frac{r}{L}$	$-9.99 \cdot 10^{-8}$	(-2.54)
L	5,266,955	(5.62)[a]
Adjusted R^2	0.82	
Durbin Watson test-statistic	1.61	

[a] t-statistic for L was estimated by non-linear regression.

According to the results presented in Table 1, the intrinsic growth rate of the biomass, r, is about 0.53 and the carrying capacity of the environment is about 5,270,000 tonnes. The estimate of the intrinsic growth rate is very close to the corresponding estimate reported by Bjørndal (1988) of 0.52. This estimate was based on estimating a delay-difference model of population dynamics. Arnason, Magnusson and Agnarsson (2000) report an estimate of the intrinsic growth rate for Norwegian spring spawning herring of 0.47. Thus, the estimate of the intrinsic growth rate presented appears to be very robust.

Based on the estimated parameters, the stock level corresponding to maximum sustainable yield, X_{msy}, is 2,635,000 tonnes, with a corresponding maximum sustainable yield (MSY) of 698,275 tonnes.

Bjørndal and Conrad (1987) used Norwegian purse seine data for the period 1963 – 1977 to estimate a Cobb-Douglas production function. They obtained:

a = 0.06157

b = 1.3556

g = 0.5621

The parameter estimates show that the Schaefer production function is inappropriate for the North Sea herring fishery. The parameter g reveals as expected, the output elasticity of stock size to be between zero and one. Thus, harvest will decrease with decreasing stock size, but is not very sensitive to changes. The parameter b indicates an output elasticity of effort larger than one. This means that increased effort is met with increasing harvest. This may be the result of economies of scale in the search for schools of herring.

Bjørndal and Conrad (1987) also estimated the production function for a pure schooling fishery as a special case. With g = 0 imposed they obtained the following parameter estimates for the Cobb-Douglas production function by OLS regression:

$a_s = 93.769$

$b_s = 1.4099$

Even if the Cobb Douglas functional form $Y_t = aK_t^b X_t^g$ resulted in the most plausible values for the bionomic equilibrium and open access dynamics (Bjørndal and Conrad, 1987), the pure schooling fishery is an interesting case. As pointed out by Bjørndal (1988) the optimal stock levels under this assumption are always less than or equal to optimal stock levels with density-dependent costs.

Several countries harvest the North Sea herring stock. By estimating the production function using data for the Norwegian purse seine fleet, the fishing effort, K, may be interpreted as an estimate of "purse seine equivalents" fishing herring in the entire North Sea (Bjørndal and Conrad, 1987).

Cost data for the Norwegian purse seine fleet will be used. The Norwegian Directorate of Fisheries annually collects cost data for a sample of vessels. Cost data for purse seine vessels with cargo capacity 8,000 hl and above will be used in the analysis. Fixed costs will be disregarded, because the vessels in question participate in several seasonal fisheries in addition to the North Sea herring fishery. This is appropriate, as the North Sea herring fishery is relatively minor compared to other fisheries and does not require any special equipment.

The price used is average price paid to the boat owners for North Sea herring, adjusted by a factor of 0.65, which represents the boat owner's share of income. Adjusted prices and relevant costs for the period 1998 to 2000 are shown in Table 2. See Nøstbakken (2002) for a more thorough discussion.

Table 2: Price per tonne, variable costs in vessel group 028 and the North Sea herring fishery's share of the costs, 1998 – 2000 (in NOK).

Year	1998	1999	2000
Price	1,423	1,137	1,280
Variable costs			
Fuel	978,553	1,431,098	2,288,973
Bait, ice, salt and packaging	18,622	239,599	457,722
Miscellaneous	1,449,646	2,373,542	2,074,123
Total variable cost	2,446,821	4,044,239	4,820,818
Number of fishing days	260	250	273
Variable cost per fishing day	9,411	16,177	17,659
Fishing days, North Sea herring	60	60	60
Variable cost, North Sea herring	564,700	970,600	1,059,500

Source: The Norwegian Directorate of Fisheries (1999-2001).

Table 2 shows a substantial increase in costs from 1998 to 2000. The increase was particularly large from 1998 to 1999. One explanation is that a relatively large number of vessels were replaced from 1998 to 1999. In addition the price of fuel has increased considerably during the period.

The equilibrium supply curves

Using the estimated parameters, we are now able to derive equilibrium supply curves. The open access equilibrium supply curve for the cost c = 1,059,500, is shown in Figure 1. c = 1,059,500 represents the cost per purse seine vessel in the North Sea herring fishery in 2000 (see Table 2). The shape of the curve is backward bending as a consequence of the biological overfishing that occurs when effort exceeds the level corresponding to maximum sustainable yield (Clark, 1990).

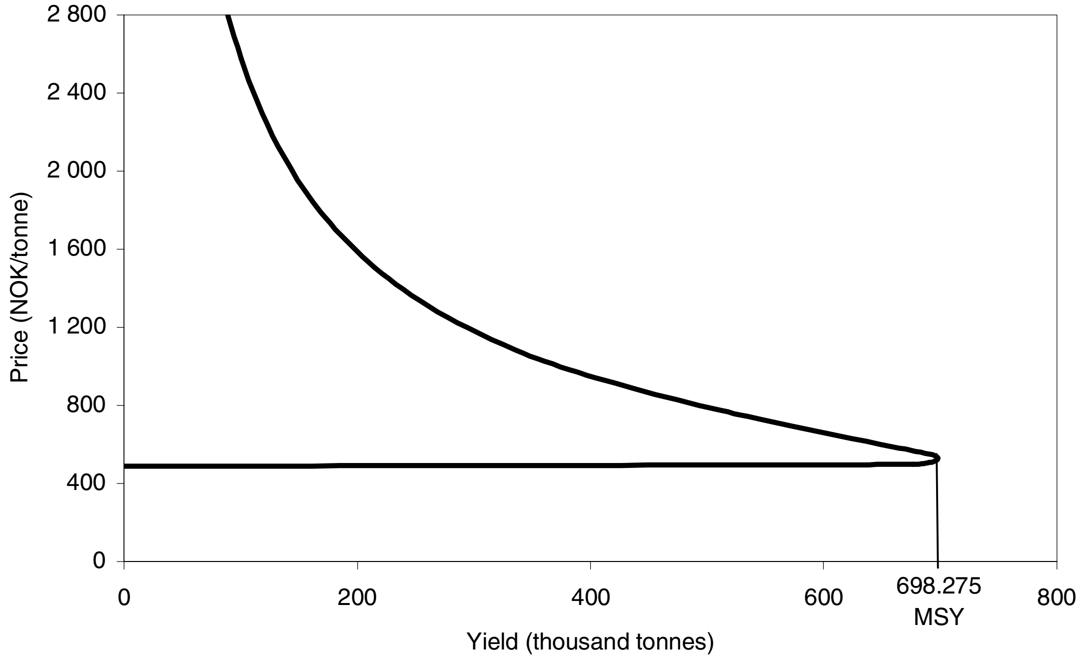

Figure 1: The open access equilibrium supply curve, c = 1,059,500 NOK.

The supply will be zero if the adjusted price is 481 NOK/tonne or less. The reason is that fishing will not be viable at such low price levels. For prices above 481 NOK/tonne, the supply increases to the maximum sustainable yield (MSY), and subsequently decreases toward zero again. MSY = 698,275 tonnes is reached when the price is 528 NOK/tonne.

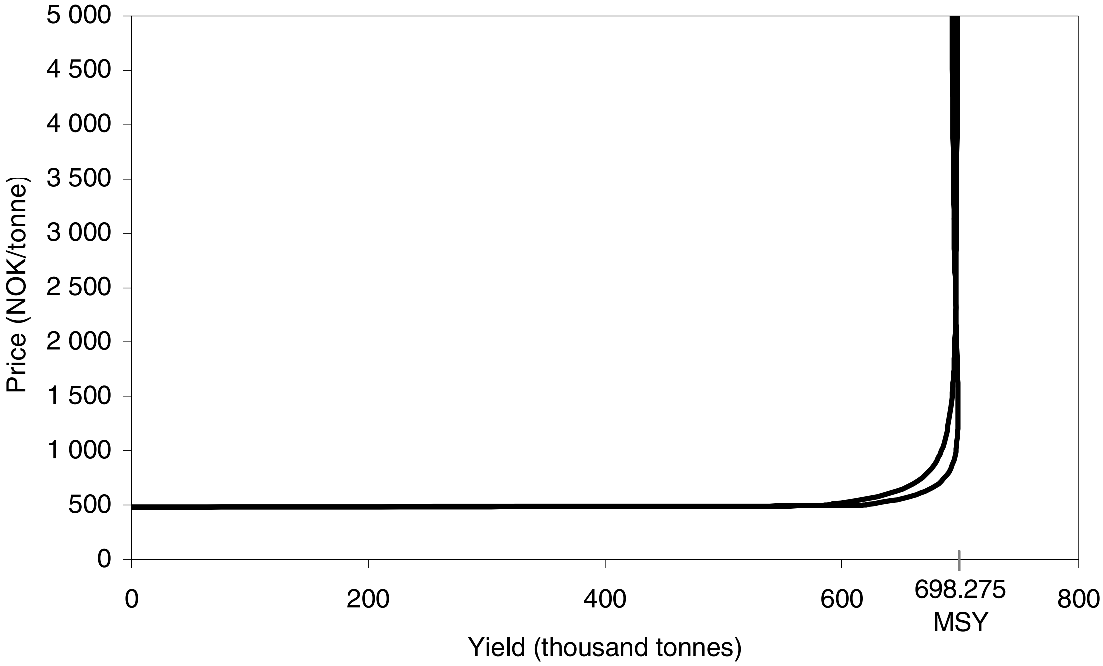

Figure 2: The discounted supply curve. c = 1,059,500 NOK, ρ = 6% (black line) and ρ = 0.

Figure 2 shows the equilibrium supply curve for the optimally managed fishery when c = 1,059,500 and alternative discount rates of 0% and 6%. For $\rho > 0\%$ the discounted supply curve is backward bending, but the degree of backward bending depends on the rate of discount employed. For small ρ, the degree of backward bending will be modest. For ρ = 0%, the supply approaches MSY as price increases.

Similar to the case of open access, the discounted supply will be zero if the price is 481 NOK/tonne or less. If the discount rate is 6%, the supply will increase with price until p_{msy} = 1,355 NOK/tonne is reached and the supply is MSY = 698,275 tonnes. Subsequently the supply decreases towards a level of 689,325 tonnes. Thus, even large changes in the price will not affect the discounted supply very much.

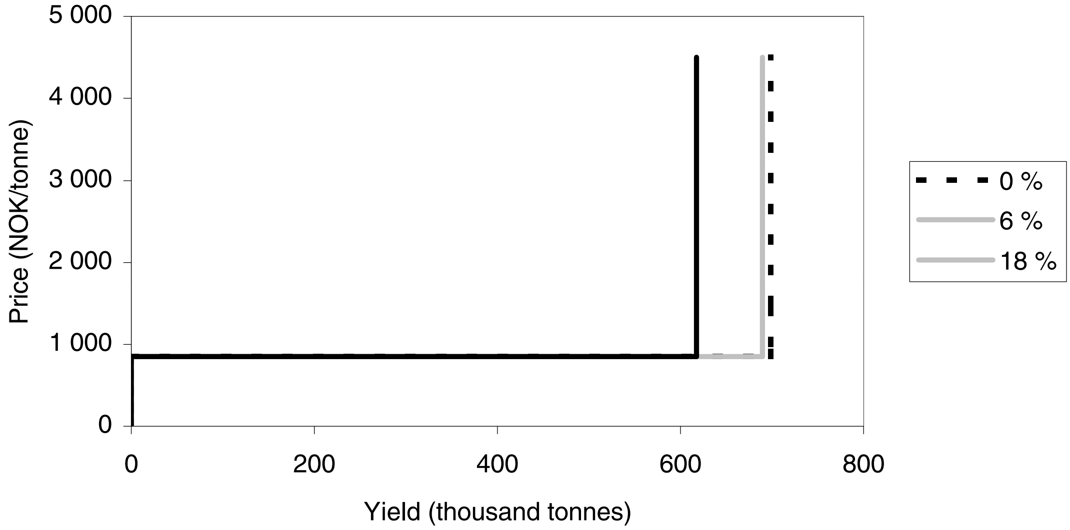

Figure 3: Equilibrium supply curves for the optimally managed pure schooling fishery. c = 1,059,500 NOK and ρ =0, ρ =6% and ρ =18%.

Figure 3 shows equilibrium supply curves for the optimally managed pure schooling fishery. In the pure schooling fishery the equilibrium supply will be zero if the price is less then 849 NOK/tonne. For prices above 849 NOK/tonne, the equilibrium supply is positive and independent of price as long as $\rho \leq r$. If $\rho > r$ the stock will be driven to extinction and the equilibrium supply will be zero. The equilibrium supply is decreasing in the rate of discount. For prices above 849 NOK/tonne the supply is MSY = 698,275 tonnes for ρ = 0% and 689,325 tonnes for ρ = 6%. This corresponds to the yields the discounted supply curves in Figure 2 approaches as $p \to +\infty$. Thus, the optimally managed pure schooling fishery represents limits for the optimal stock level.

Sensitivity analysis

The open access equilibrium supply curve is most sensitive to changes in the parameters of the production function; especially for changes in the parameters b and g. Changes in costs have a moderate effect on the open access supply. The supply curves for the optimally managed fisheries are most sensitive to changes in the biological parameters. They are not very sensitive to changes in the discount rate. The effect on the discounted supply curve of changes in costs is small.

4. Effects of Regulations

We will now analyse the effect of actual regulations on the supply of North Sea herring and compare these to the open access and optimally managed fishery. The cases of open access and optimal management represent extremes. Very few, if any, real world fisheries are under such regimes, but the two extreme cases are of interest as benchmarks for other regulations. The following discussion will be divided into two, the period before and after 1996, because of an evident change in the regulatory regime this year.

a. Regulations 1981 – 1996

After a moratorium the fishery was reopened in the southern North Sea in 1981 and in the central and northern North Sea in 1983. In 1983 the total biomass was about 2.7 million tonnes. From 1983 to 1988 there was a large increase in catches, resulting in a total catch of 888,000 tonnes in 1988. With MSY = 698,275 tonnes, the landings during the mid-1980s were clearly not sustainable.

Based on price and cost data from 1984, we can calculate the equilibrium supply and corresponding stock and fishing effort under the optimally managed fishery and open access fishery. The results are shown in Table 3. The optimal stock level is about 2.65 million tonnes. This is about the same as the actual stock level in 1983. To maximise the resource rent from the stock, one should therefore have harvested 698,000 tonnes per year. Instead of this, the stock was gradually reduced outside the safe biological level, because of extensive harvesting. Without any regulations in the fishery Table 3 shows that the stock would have been reduced to a level of 550,000 tonnes, with annual catches of about 260,000 tonnes. Bjørndal and Conrad (1987) use a discrete time model to analyse the dynamics of an open access fishery. They argue that with a discrete model there is a greater likelihood of overshoot, severe depletion and possible extinction. Thus, we might have depletion because of overshooting in the open access case, instead of the stated equilibrium.

Table 3: Equilibrium under open access fishery and optimally managed fishery, P = 585 NOK/tonne and c = 473,800 NOK. (Harvest and stock in tonnes, fishing effort in number of purse seine equivalents.)

	Harvest (Y)	Stock (X)	Fishing effort (K)
Open access fishery	261,100	550,000	322
Optimally managed fishery	698,300	2,647,900	347

The actual regulations in the North Sea herring fishery from the early 1980s to 1996 were not optimal, because they did not maximise rent. However, there were some regulations of the fishery, distinguishing it from the open access regime. Without these regulations, the stock would probably have been reduced at a faster pace than observed. In this way the regulations prevented the fishermen from catching even more herring, although the actual catches were far from sustainable. The regulatory regime might therefore best be termed "regulated open access" (Homans and Wilen, 1997).

b. Regulations 1996 -

In May 1996 Norway and the European Union agreed on severe reductions in total quota to save the North Sea herring stock from collapse. From 1998 the EU-Norway agreement has been in effect. To rebuild the stock to an acceptable level, the quotas have been relatively small from 1996 to 2002. In 2002 the spawning stock exceeded 1.3 mill. tonnes, the limit defined by the EU-Norway agreement.

From 1996 onwards the quotas agreed on by the EU and Norway, have been set according to recommendations from the International Council for the Exploration of the Sea (ICES). For this reason we also expect the quotas for 2003 to follow ICES recommendations. In this case the TAC for the North Sea area[4] will increase from 265,000 tonnes the last couple of years, to 450,000 tonnes in 2003.

[4] ICES Subarea IV and Division VIId. Autumn spawning North Sea herring is also caught in Skagerrak and Kattegat (Division IIIa).

Both prices and costs appear to have changed considerably from 1998 to 2000. For this reason the equilibrium supply will depend on what year the analysis is based on. Table 4 shows equilibrium supply and corresponding stock and fishing effort for the years 1998, 1999 and 2000. The table also shows the actual harvest and stock level each year.

Table 4: Equilibrium under open access fishery and optimally managed fishery according to prices and costs in 1998, 1999 and 2000. (Prices in NOK/tonne, costs in NOK, harvest and stock in tonnes, fishing effort in number of purse seine equivalents.)

	1998	1999	2000
Price (p)	1,423	1,137	1,280
Cost (c)	564,700	970,600	1,059,500
Open access fishery:			
Harvest (Y_∞)	95,300	280,500	269,000
Stock (X_∞)	186,300	596,800	568,900
Fishing effort (K_∞)	240	329	325
Optimally managed fishery[a]:			
Harvest (Y^*)	695,700	698,200	698,200
Stock (X^*)	2,475,100	2,668,300	2,656,200
Fishing effort (K^*)	356	346	347
Actual state[b]:			
Harvest	380,200	372,300	372,400
Stock	2,189,700	2,454,400	3,118,900

[a] Discount rate ρ = 6%.
[b] Source: ICES, 2002a.

While the equilibrium supply is quite stable during the three years in the case of an optimally managed fishery, the opposite is true for the open access fishery. Under an open access regime the equilibrium supply would be 95,000 tonnes in 1998 and 280,000 tonnes in 1999. As can be seen in Table 4, the corresponding stock levels are 186,000 tonnes and 597,000 tonnes. According to ICES the minimum biological acceptable level for the North Sea herring spawning biomass is 800,000 tonnes. With a total biomass of less than 600,000 tonnes, the stock would have been in danger of extinction under an open access regime.

If the fishery were optimally managed, the stock would be about 2.6 million tonnes in all three years as indicated by Table 4. The actual stock level in 2000 was about 3.1 million tonnes. Despite this, the quotas have been kept relatively small in 2001 and 2002 to let the stock grow even more. According to data for the year 2000 in Table 4, a stock of 2.66 million tonnes with corresponding annual harvest of 698,200 tonnes would maximise the rent from the stock. Thus, annual harvest would be almost as large as the maximum sustainable yield.

For the year 2000 the optimally managed fishery involves a fishing effort of 347 purse seine equivalents in the North Sea herring fishery. This would on average allow each purse seine equivalent to annually harvest about 2,010 tonnes. In 2001 the total North Sea herring landings was 364,000 tonnes. By assuming that each purse seine equivalent catches as much North Sea herring as the average Norwegian purse seiner, we find that 498 purse seine equivalents participated in the North Sea herring fishery in 2001. Thus, the actual fishing effort in 2001 was considerably greater than under an optimally managed regime. In addition to this the total catch was smaller, resulting in a much smaller average catch per purse seine equivalent in the actual fishery than in the optimally managed fishery.

The fact that the EU and Norway did not increase TAC in 2001 or 2002, indicate that they want to stabilise the stock at a higher level than what maximises economic rent according to our analysis. ICES (2002b) gives different catch options for 2003, which reflect both the ICES recommendations and the EU-Norway agreement. All scenarios result in a spawning stock of 2.2 million tonnes and a total catch between 620,000 and 635,000 tonnes. If the EU and Norway continue to follow ICES recommendations, this indicates stabilisation with an annual harvest of about 630,000 tonnes. Using the logistic growth function from equation (2), we estimate the corresponding total biomass level to be 3.5 million tonnes.

The regulatory regime that has been in force since 1996 appears to result in a lower supply of North Sea herring than what would have been the case if the fishery were optimally managed. Because of the shape of the logistic growth function, moderate reductions in the stock would have increased the sustainable yield.

c. The effect of the 1996 change in regulations

The change in regulations in 1996 seems to have had considerable effects on both stock level and supply. Before 1996 the annual landings was unsustainable. This caused the stock to decrease every year, and from 1992 onwards the stock was smaller than the stock level under an optimally managed fishery. After the change in 1996 the stock increased from year to year, and from 2000 onwards the stock has been larger than the optimal level. This development is illustrated in Figure 4.

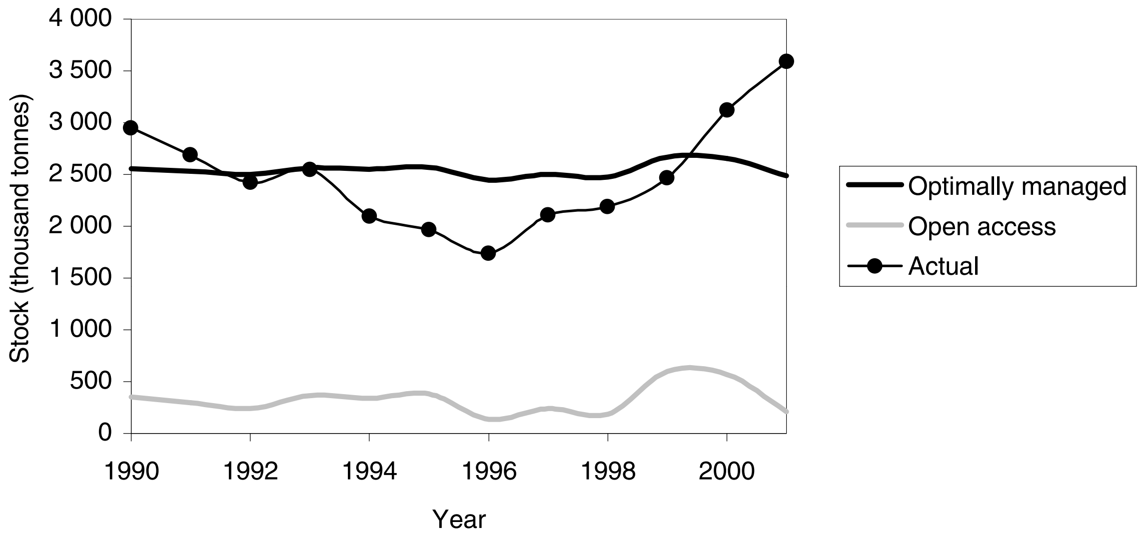

Figure 4: Equilibrium stock under open access[a] and optimally managed fishery[a,b], and actual stock[c], 1990-2001.

[a] The 2001 equilibrium stocks is based on costs in 2000.
[b] Discount rate ρ = 6%.
[c] Source: ICES, 2002a.

The change in regulations in 1996 is also evident in Figure 5. This figure shows equilibrium supply under open access and optimal management, together with actual supply and calculated sustainable yield based on actual stock level[5]. The optimally

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[5] Sustainable yield (Y_A) based on actual stock level (X_A) is calculated as follows: $Y_A = rX_A\left(1-\frac{X_A}{L}\right)$

managed fishery results in the highest supply, while the open access fishery results in the lowest supply. The difference between actual catches and estimated catches based on actual stock level is relatively large. This is a consequence of the fishery not being in equilibrium. As expected, the difference is particularly large after 1996.

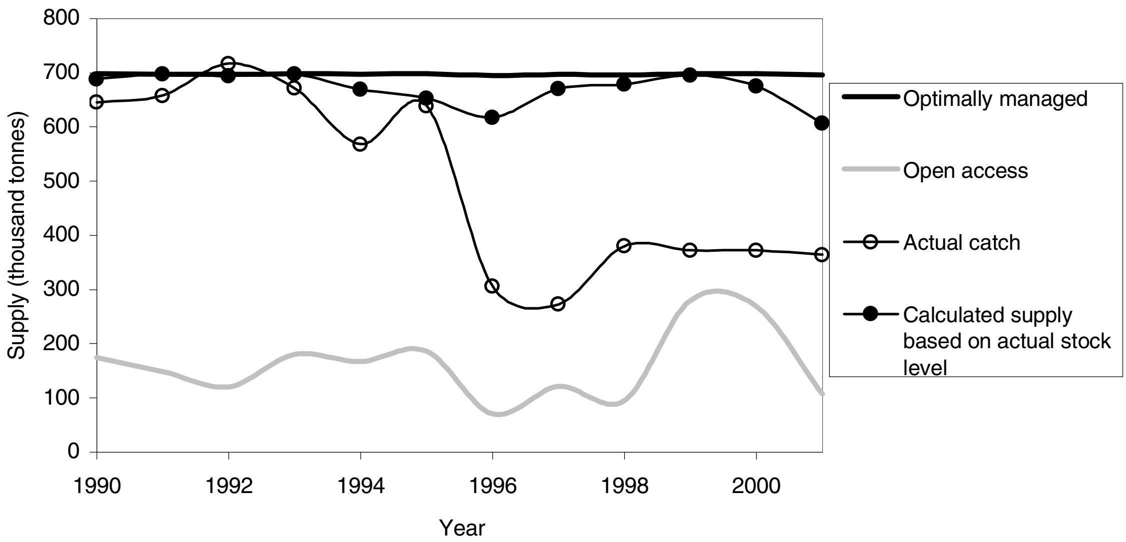

Figure 5: Equilibrium supply under open access fishery[a] and optimally managed fishery[a,b], together with actual supply[c] and calculated equilibrium supply based on actual stock level[c], 1990-2000.

[a] The 2001 equilibrium supply is based on costs in 2000.
[b] Discount rate ρ = 6%.
[c] Source: ICES, 2002a.

5. Summary

Different regulations can have a substantial impact on the supply of North Sea herring. It has been argued that the annual equilibrium supply can vary from zero in case the stock is driven to extinction under open access, to a sustainable annual yield of 690-700 thousand tonnes. The reason for this difference is the effective means of harvesting schooling fish stocks, which makes the harvesting of herring economically viable even at very low stock levels.

In this paper we have derived and estimated equilibrium supply curves for the open access fishery and the optimally managed fishery. A sensitivity analysis was subsequently carried out. This analysis showed that the open access supply curve was most sensitive to changes in the parameters of the production function, while the discounted supply curve was most sensitive to changes in the biological parameters. Moderate changes in the discount rate were found to have little effect on equilibrium supply.

Different regulations, both actual and theoretical, were evaluated with respect to effects on supply, stock level and fishing effort. A change in the actual regulations is evident in 1996. From 1996 onwards the quotas have been relatively small. This has allowed the stock to approach a higher level than the one that maximises rent. Because of this the annual supply is smaller than in an optimally managed fishery. However, the supply would have been much smaller under an open access regime.

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