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Climate Change and its Effect on the Norwegian Herring Fishery

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Abstract

The effects of climate change on revenues in the Norwegian herring fishery are considered. The catch quota of Norwegian spring spawning herring is assumed to increase by 25% as a result of warming of the Norwegian Sea and the Barents Sea. Two cases are considered, one with a constant price and one with a quantity-dependent price. The latter relationship is based on data for prices and landings for 1970-2001. The scenario where price and quantity are independent of each other shows that the average gross revenue will increase by about 300 million Norwegian kroner per year. Because price and quantity change randomly over time, the climate induced increase can fluctuate between the extremes of 180 to 450 million kroner per year. The price-quantity dependent models show that a 144 thousand tons climate-induced increase in the Norwegian catches of herring represents a gross value between 100 and 130 million Norwegian kroner per year.

1. INTRODUCTION

The background for this paper is the expected global warming and its possible economic effects on natural resource based industries. The paper focuses on the potential effects of expected long run climate change on the Norwegian herring fisheries.

Most of the Norwegian catches of herring derive from two separate, but highly substitutable herring stocks, North Sea herring and Norwegian spring spawning herring, the latter inhabiting the Norwegian Sea and the Barents Sea. Of these, the Norwegian spring spawning herring is the most important. Hence the climate changes discussed are mainly the ones expected to occur in the Norwegian Sea and the Barents Sea.

The Norwegian Economic Zone (NEZ) in the Barents Sea is one of the most productive marine ecosystems in the world due to the supply of zooplankton-rich Atlantic water from the Norwegian Sea (Stenevik and Sundby 2004). About 40% of the total area of the Barents Sea falls within the NEZ. The long run climate scenario for this area predicts that the average temperature will increase and that the Polar Front will be pushed further north, so that the Barents Sea will become ice free (Sundby 2004, Addendum). This scenario implies that the ecosystem producing the herring will expand, because of higher temperature and increased supply of zooplankton. The ice-free area would expand towards north and east, and the process is expected to have a positive effect on the Norwegian spring spawning herring stock.

The catch of herring – totally and for each country – has fluctuated over the years. A climate induced increase of herring by about 20 to 30 % (Sundby 2004, Addendum) refers to an increase from average catches over the past 10 years.

Even if climate change would increase the stock of herring and subsequently the catch quota and landings, the revenues in the fishery would not necessarily rise proportionately. The price of fish may depend negatively on the quantity landed, implying that revenues would rise less than proportionately with landings. In this paper we will investigate the possible interdependence between price and quantity. The paper deals with the possible change in the revenue from fishing resulting from climate change, but does not consider possible changes in the costs of fishing.

The paper is structured as follows. The next section introduces the problem to be analyzed. Section Three is descriptive and gives a short overview over the landings and catches of herring in Norway and in the rest of the Northeast Atlantic area. In Section Four we estimate the relation between price and quantity landed of herring. Section Five analyses the impact on the revenue in the herring fishery from the expected climate changes. Section Six concludes.

2. THE DEMAND FOR HERRING

The final demand for herring (y_H), or whatever commodity, is determined by the price of herring (p_H), prices of substitutes and complements (p_S), and the income level (I). The inverse (Marshallian) uncompensated demand function can be expressed in the following way:

$$y_C = D(p_C, p_S, I)$$

The fish processing industry's demand for herring is derived from the underlying demand for the commodity which the industry produces. The processing industry's demand for herring as input is a function of the raw fish price of herring, prices of substitutes and complements for herring, and the price of the final product. In the following we are referring to the input demand for herring.

The fisheries for herring are regulated by a limit on the total catch, usually referred to as TAC (total allowable catch). Given that these regulations are reasonably effective and that it is profitable to catch the entire TAC, the supply of herring is given by the TAC. Analytically the supply curve can then be treated as an inelastic supply function, but shifting over time as the TAC is changed from one year to another. Hence, in this paper, it will be assumed that the supply of herring is equal to the TAC. Figure 1 shows the initial market equilibrium for herring, i.e. (p_0, y_0)

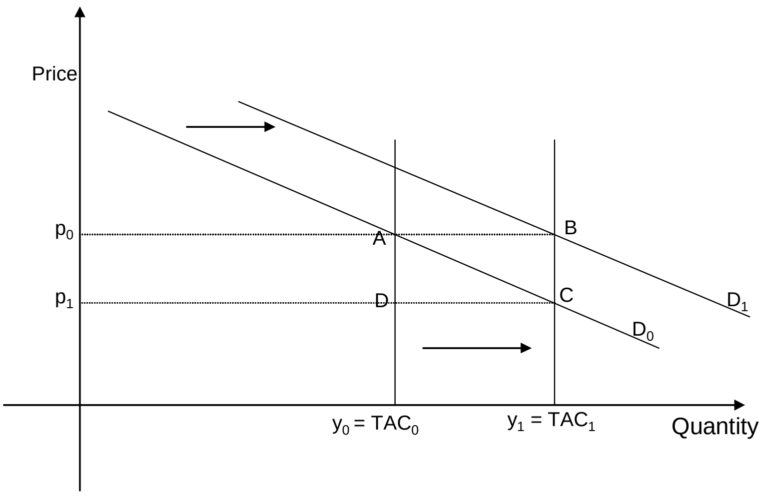

Figure 1: Demand and quota determined supply of herring

If the quota of herring increases from TAC_0 to TAC_1, the supply curve of herring will shift to the right and, given a downward sloping demand curve, the price must be reduced to reach equilibrium. The price is reduced from p_0 to p_1, as is illustrated in the figure. The new equilibrium is expected if income, preferences, prices of substitutes, and technology are constant.

The climate induced changes are supposed to evolve over time, and it is also expected that preferences, incomes, and prices of substitutes will change over time. Changes in these parameters will generate shifts in the demand curve for herring. Figure 1 also illustrates a positive shift in the demand curve from D_0 to D_1, where the shift keeps the real price of herring at the initial p_0-level, even though the quota and landings of herring have increased. In the following we will ignore changes in demand and concentrate on changes in supply (TAC) effectuated by climate change.

To evaluate the effect of climate change on revenue in the fishery, we must estimate the climate induced change in quantity landed (Δy) and the effect on the expected price of herring (p_H). The change in quantity could be negative or positive, depending on biological factors. Suppose that the price level is constant, i.e. that the demand is infinitely elastic at the price level p_H. The climate induced change in gross revenue (ΔR) will then be

$$\Delta R = \Delta y p_H$$

Figure 1 illustrates this scenario, given that the price level of herring is constant. With reference to the figure the change in gross revenue is $\Delta R = (y - y_0)\, p_0$. To be able to quantify or estimate ΔR is a question of having valid numbers for, respectively, Δy and p_H.

The above expression for the gross increase in revenue induced by the increase in catches did not take into account that the real price of herring could be affected by an increase in the supply of herring. It is an empirical question whether the demand is sensitive to changes in quantity or not. Figure 1 illustrates this situation. Suppose that TAC increases from y_0 to y_1, and that the demand curve D_0 is stable. An increase in TAC implies that the price is reduced from p_0 to p_1. The change in revenue is $\Delta R = p_1 \Delta y + \Delta p y_0$. If the price level is a function of quantity supplied, then the gross increase in revenue can be expressed in the following way, given constant elasticity for the analysed interval:

$$\Delta R = p_0 (1 + \frac{1}{\varepsilon}) \Delta y$$

where ε is the uncompensated own price elasticity of herring, i.e.

$$\varepsilon = \frac{\partial y_H \, p_H}{\partial p_H \, y_H} < 0 .$$

Hence, for calculating the change in the gross revenue, we need estimates of the change in quantity supplied Δy, initial real price level p_0, and the elasticity of demand ε. Whether the change in gross revenue ΔR is positive or not depends on the value of the elasticity of demand for herring ε. Given that $\Delta y > 0$, $\varepsilon < -1$ implies that $\Delta R > 0$ and $\varepsilon > -1$ implies that $\Delta R < 0$. Thus it is possible that an increase in landed quantity would lead to a decrease in revenues, but the low demand elasticity (less than one in absolute value) necessary for producing this result is highly unlikely to obtain for herring, and is certainly not implied by the econometric analysis to be discussed below. That notwithstanding, this illustrates that a negative effect of greater landings on the market price could substantially reduce the increase in revenues otherwise expected to result from greater landings.

The welfare economic effects of greater landings of fish can be expressed as the sum of changes in producer and consumer surplus, i.e. $\Delta W = \Delta PS + \Delta CS$. Most of the fish landed in Norway is exported, which implies that we can neglect the changes in consumer surplus. Hence, if $\Delta R > 0$, it implies that the gross welfare effect is positive.

The estimation of the quantity effect Δy depends solely on the climate scenario while the estimation of the price effect depends on how the market reacts to changes in the quantity supplied. Based on time series data we have tested whether there is an interrelation between quantity and price. The analyses are based on annual data from the time period 1970-2001 on the real price of herring, the landed quantity of herring in Norway by Norwegian vessels, the landed quantity of herring in Norway by foreign vessels, and the total catch of herring in the Northeast Atlantic.[1]

3. THE HERRING INDUSTRY

As already stated, there are two herring stocks to be considered, North Sea herring and the Norwegian spring spawning herring. The habitat of the most important stock, the Norwegian spring spawning herring (NSSH), is the northernmost part of North Sea, the Norwegian Sea, and the Barents Sea. Oceanographers and fisheries biologists expect that climate change will make the Barents Sea a relatively more important area in the future, especially for juvenile herring. In general it is to be expected that the growth conditions for herring will improve as a consequence of global warming. The climate change is assumed to increase the stock about 20 to 30% because of the increase in habitat (Sundby 2004, Addendum). A negative effect is that the predation on juvenile herring will increase because the mackerel stock will probably migrate further north.

North Sea herring is caught in Skagerack and Kattegat, as well as the North Sea itself. It is expected that climate change will increase the immigration of new species – first of all pelagic species as anchovy and sardine. The increase of new species in the North Sea, and a general temperature increase, will probably make the North Sea less attractive for the herring stock. We nevertheless suppose that the North Sea herring stock will remain on the same level as during the last five years. The North Sea herring is shared by EU and Norway, with Norway's share of the TAC being on a gliding scale, depending on the abundance of the stock. Recently it has been 29 %.

The NSSH is a straddling fish stock. It spawns off the coast of western Norway during the late winter/early spring, and its offspring are transported by the coastal current northwards to the Barents Sea. After spawning, mature herring follow a clockwise feeding migration in the Norwegian Sea, returning to the fjords in Northern Norway in the autumn (Sandberg, 2004). Its present feeding migration pattern takes it into the high seas area in the Norwegian Sea and the exclusive economic zones (EEZ) of the Faeroe Islands and Iceland. Figure 1 shows the recent distribution of herring (ibid 2004). For an overview of the migrations of the NSSH stock, see Sissener and Bjørndal (2005).

The TAC of NSSH is shared by five parties, Norway, Russia, the Faeroe Islands, EU, and Iceland. Since 1996 the parties have agreed to regulate the annual harvest from the stock by a total allowable catch (TAC) and thereafter divide it by fixed shares. Since 2003 the question of allocation has been reopened, with all parties wanting a higher share. Norway is for example not satisfied with the 57% of the TAC previously agreed. The parties did not reach any agreement for 2004 in spite of a number of meetings on the issue, and so far not for 2005 either.

Based on Sundby (Addendum 2004) we assume that the landings of NSSH will increase in the future by about 25% compared to the average of the last 10 years of landings. Figure 3 shows the quantity and the unit price (2003-value) of the NSSH and the North Sea herring during the period 1970 to 2001. The figure shows a tendency to an inverse relationship between price and quantity landed. The total quantity of landed fish has increased from the mid 1970s due to

[1] For a definition of the Northeast Atlantic, see Appendix 1. Sources: Statistics Norway and ICES Fisheries Statistics 1973-2001, Nominal Catch Statistics STATLANT Programme.

a successful rebuilding of the stock (Lorentzen and Hannesson 2004). The real price had a six year positive trend period before 1979 and a five year negative trend period after 1979. Thereafter the real price has no trend, but the figure indicates that the price responds to changes in quantity. Figures 4 and 5 further explore the relationship between price and quantity. Figure 4 indicates a negative, nonlinear overall relationship between price and quantity. Notice that the variance of the price increases for large quantities landed. Figure 5 shows that price and quantity on average change in opposite directions, which indicates a negative relationship between price and quantity.

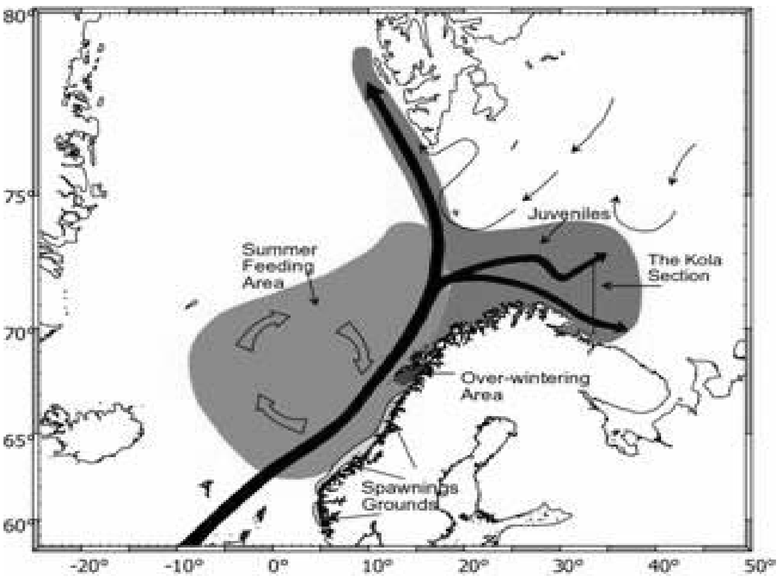

Figure 2: Migration pattern for Norwegian spring spawning herring. The grey area shows the current distribution of herring, whereas the black arrows show inflow of warm Atlantic water (the Gulf Stream)
Source: Sandberg 2004

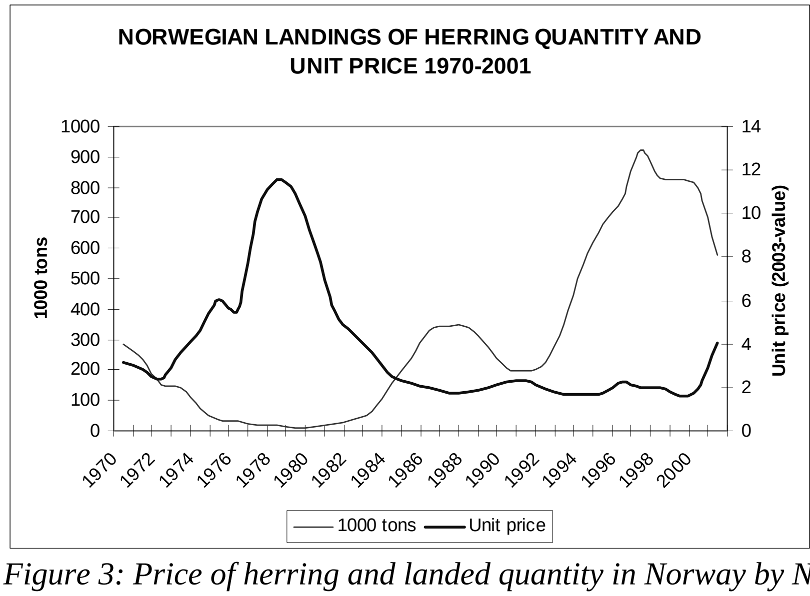

Figure 3: Price of herring and landed quantity in Norway by Norwegian vessels
Source: Statistics Norway

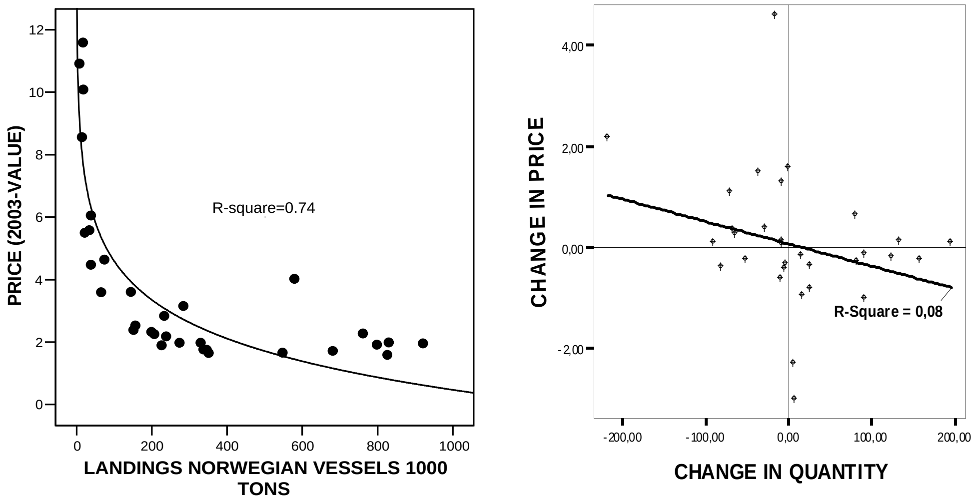

Figure 4 and 5: Unit price on herring and fish landed by Norwegian vessels 1970-2001

The landings of herring from foreign vessels, mainly from Ireland and Scotland, have increased during the 1990s (Figure 6). The increase in foreign landings can be explained partly by liberalization of foreign fish landings in Norway, partly by the fact that the EU-fleet can catch a share of its quota in the Norwegian EEZ, and partly by high, competitive prices in the Norwegian raw fish market.

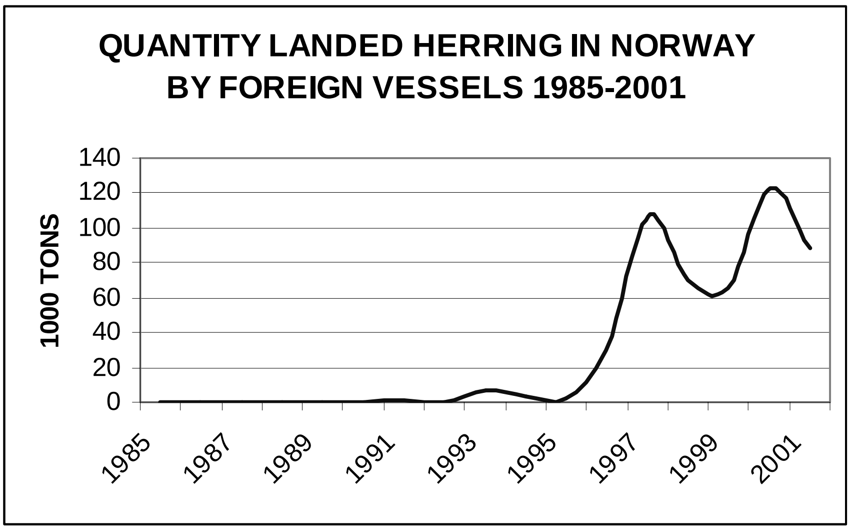

Figure 6: Foreign vessels landings of herring in Norway
Source: Statistics Norway

The pelagic industries in Scotland, Ireland and the Faeroe Islands have recently invested in processing capacity and upgraded their factories, and it is expected that the landings of herring in Norway will be reduced in the future. The landing pattern will also be influenced by the future migration pattern of the herring. Figure 7 shows the total catch of herring in the Northeast Atlantic during the period 1970-2001.

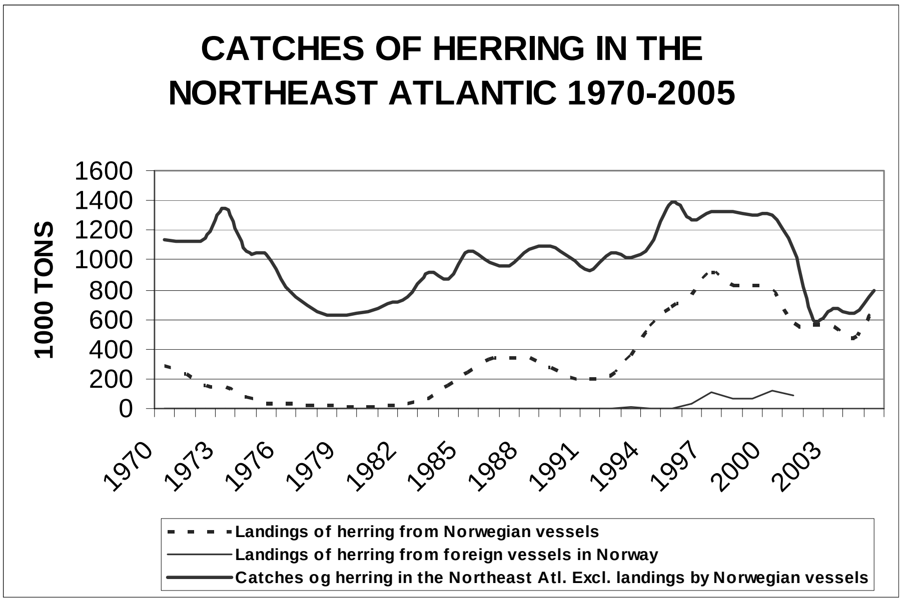

Figure 7: Aggregated catches of herring in the Northeast Atlantic
Source: Statistics Norway and ICES

Figure 7 shows that the catch of herring in the Northeast Atlantic has fluctuated during the period 1970-2005 (numbers for 2004 and 2005 are estimates). There is an overall positive trend in the 1980s and 90s, which was reversed at the turn of the century. Fisheries biologists expect that the TAC will increase to about one million tons in the coming years (Institute of Marine Resources in Norway 2005). Figure 8 shows the aggregated real export value and quantity of herring during the 1988-2003.

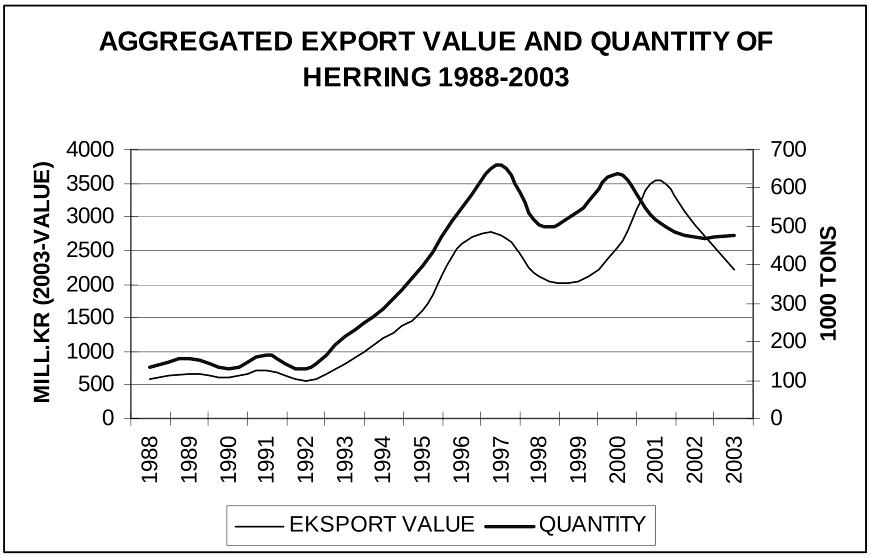

Figure 8: Aggregated export of herring from Norway
Source: Statistics of Norway

The relatively low and constant export level in the early 90s was succeeded by an export boom which ended in the last part of the 90s. The boom can be explained among other factors by the growth in quotas and increased landings from foreign vessels. The average export value in the last eight years is about 2.6 billion Norwegian kroner (2003-value). The last two-three years the export value and quantity is reduced.

4. ESTIMATION OF DEMAND FUNCTIONS

Two models are used for estimating the relation between quantity and price. Both of these are price-dependent demand models, as the aggregated supply of herring is assumed exogenously given by the TAC. It may be added that the argument for identification and validity of the analysis is weakened if the demand of herring is *not* stable over time. Different functional forms can be used for this purpose, for example log-linear or the more flexible Box-Cox-function. We have applied a log-linear functional form.

Figures 3 and 4 indicate that there is a negative relationship between price and quantity. The Pearson's correlation matrix in table 1 shows that there is a significant, negative relation between, respectively, price and quantity landed by Norwegian vessels, price and aggregated catches (excluding landings from Norwegian vessels) in the Northeast Atlantic, and price and total landings in Norway. The volume or quantity variables are positively correlated, which indicate that the variables on average follow the same path of development.

Table 1: Person's Correlation matrix

		Unit price (p)	Quantity Norwegian vessels (x_1)	Total landings of herring in Norway (x_2)	Total landings in NEAT excl. Norwegian vessels (x_3)	Landings by foreign vessels in Norway (x_4)
Unit price (p)	Pearson Correlation	1	-.589(**)	-.564(**)	-.721(**)	.313
	Sig. (1-tailed)		.000	.000	.000	.128
	N	32	32	32	32	15
Quantity Norwegian vessels (x_1)	Pearson Correlation	-.589(**)	1	.998(**)	.828(**)	.777(**)
	Sig. (1-tailed)	.000		.000	.000	.000
	N	32	32	32	32	15
Total landings of herring in Norway (x_2)	Pearson Correlation	-.564(**)	.998(**)	1	.821(**)	.833(**)
	Sig. (1-tailed)	.000	.000		.000	.000
	N	32	32	32	32	15
Total landings in NEAT excl. Norwegian vessels (x_3)	Pearson Correlation	-.721(**)	.828(**)	.821(**)	1	.733(**)
	Sig. (1-tailed)	.000	.000	.000		.001
	N	32	32	32	32	15
Landings by foreign vessels in Norway (x_4)	Pearson Correlation	.313	.777(**)	.833(**)	.733(**)	1
	Sig. (1-tailed)	.128	.000	.000	.001	
	N	15	15	15	15	15

** Correlation is significant at the 0.01 level (1-tailed).

Notice that the price level is not negatively affected by foreign quantity landed in Norway. Figure 9 maps the relation between price and quantity landed by foreign vessels.

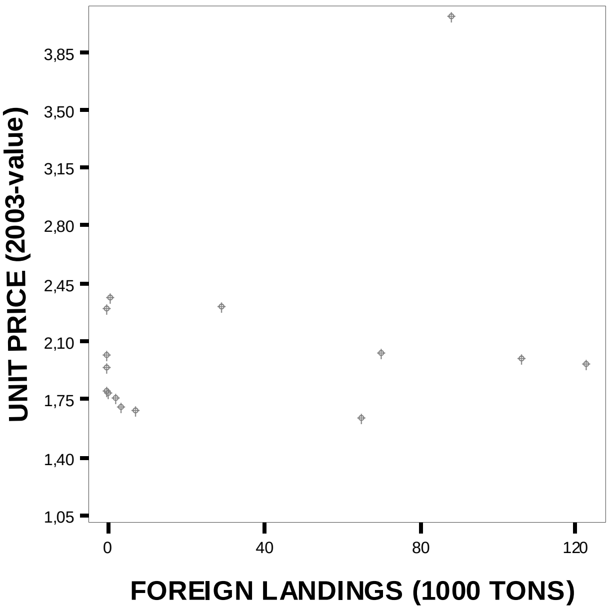

Figure 9: Unit price and foreign landings in Norway

How can we explain that there is no significant correlation between the price of herring in Norway and foreign landings? The reason probably is the time pattern of the fishery. The Norwegian fleet catches the NSSH mainly in the first quarter of the year and in the period from September to December. The quality of the fish is highest in the period from September to the last part of February. The foreign fleet catches the fish in a period where the quality is not the best. The difference is explained by the migration pattern and the regulation system. The North Sea fishery continues during the summer and autumn. The fact that the different national fleets catch the fish at different points in time and that the quality of the fish changes over time imply that the effect on the price realized by the Norwegian fleet is limited.

Given the dependence of the price of herring on Norwegian landings and aggregated catches in the Northeast Atlantic, we proceed to estimate demand models. Both types of herring (North Sea herring and Norwegian Spring Spawning herring) have been aggregated into one common herring group, because they are close substitutes. Two models are estimated:

Model I: $\ln p_t = \alpha + \beta \ln q_t + u_t$

Model II: $\ln p_t = \alpha + \beta \ln q_t + \gamma \ln p_{t-1} + u_t$

α: Constant,

$\ln p_t$: Natural logarithm of price (value of Norwegian landings divided by quantity landed) year $t \in [1970, \quad 2001]$,

$\ln q_t$: Natural logarithm of quantity landed (1000 tons) of herring by Norwegian vessels year $t \in [1970, \quad 2001]$,

$\ln p_{t-1}$: Natural logarithm of lagged price $t \in [1970, \quad 2001]$,

u_t: Stochastic residual at time $t \in [1970, \quad 2001]$.

Notice that model II includes a lagged dependent variable as an explanatory variable. The Pearson's correlation coefficient indicates a negative relationship between average price of herring and landed quantity from Norwegian vessels. Tables 2, 3, 4 and 5 show the results from the estimation.

Table 2: Summary Model I

R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
				R Square Change	F Change	df1	df2	Sig. F Change	
.904	.818	.812	.26185	.818	134.729	1	30	.000	.645

The model has a high explanatory power. The adjusted $\overline{R}^2 = 0.812$, i.e. 81% of the variation in unit price can be explained by the model. The value on DW-statistics indicates positive autocorrelation. It implies that respectively R^2, t and *F*- values are inflated in relation to the true values. On the other hand the estimated coefficients are unbiased. Table 3 presents the estimated coefficients.

Table 3: Coefficients Model I

Modell I	Unstandardized Coefficients		Standardized Coefficients	t	95% Confidence Interval for B		Correlations		
	B	Std. Error	Beta		Lower Bound	Upper Bound	Zero-order	Partial	Part
Constant	3.137	.180		17.469	2.770	3.503			
Lnq_t Norwegian vessels	-.397	.034	-.904	-11.607	-.467	-.327	-.904	-.904	-.904

The estimated Model I is: $\ln \hat{p}_t = 3.137 - 0.397 \ln q_t$. The estimated coefficients are significantly different from zero. The model indicates that the quantity landed has a negative influence on the average price. The log-linear model estimates how sensitive the price is to changes in quantity: The inverse uncompensated demand elasticity is: $\frac{\partial \ln \hat{p}_t}{\partial \ln q_t} = \beta = -0.397$, and it implies that the price will be reduced by about -0.4% if the quantity landed increases by one percent.

The estimation of model II is presented in tables 4 and 5.

Table 4: Summary Model II

R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
				R Square Change	F Change	df1	df2	Sig. F Change
.921	.848	.837	.24777	.848	77.982	2	28	.000

The explanatory power has increased in model II compared with the prior model. About 85% of the variation in the unit price is explained by the model. The DW-statistics is not recorded, because it has no meaning when the model contains a lagged dependent variable as an explanatory variable. The *h*-statistics for autocorrelation in models with a lagged dependant variable was insufficient because of a negative number in the square root operator. The estimated coefficients are presented in the table 5.

Table 5: Coefficients Model II

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B		Correlations			Collinearity Statistics	
	B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
Constant	1.614	.748		2.159	.040	.083	3.146					
Lnq_t Norwegian vessels	-.202	.100	-.460	-2.033	.052	-.406	.002	-.908	-.359	-.150	.106	9.399
lnp_{t-1}	.476	.227	.474	2.097	.045	.011	.940	.908	.368	.155	.106	9.399

The estimated coefficients are significant, but the *t*-values (and *p*-values) show that the variance is higher compared to the prior analyses. The estimated model II can be expressed in the following way: $\ln \hat{p}_t = 1.614 - 0.202 \ln q_t + 0.476 \ln p_{t-1}$. The estimation shows that the landed volume from the Norwegian vessels has a significant influence on the average price. According to the model, a one percent increase in quantity reduces the price level by 0.2%. The uncompensated own price elasticity according to the model is $\varepsilon = -4.95$. The long run demand elasticity, where the price is identical year by year, is $\beta/(1-\gamma) = -2.59$. The long run uncompensated inverse demand elasticity is -0.39. In this period the average price was $\bar{p} = 3.07$ kr. per kg (2003-value), and the average landings were $\bar{q} = 156.2$ thousand tons per year. The model indicates that there is a negative relation between quantity and price. Figure 10 shows how, respectively, models I and II predict the price. Figure 11 shows the covariance between estimated and observed price and landed Norwegian landings of herring.

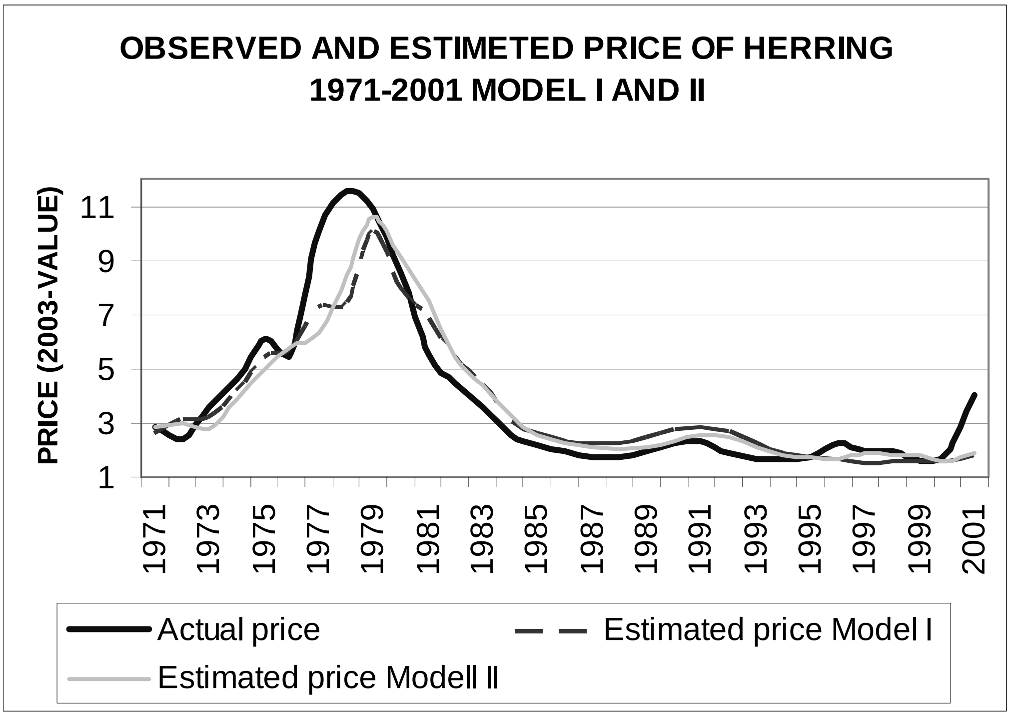

Figure 10: Observed and estimated price of herring during 1971 to 2001 Figure 10: Observed and estimated price of herring during 1971 to 2001.

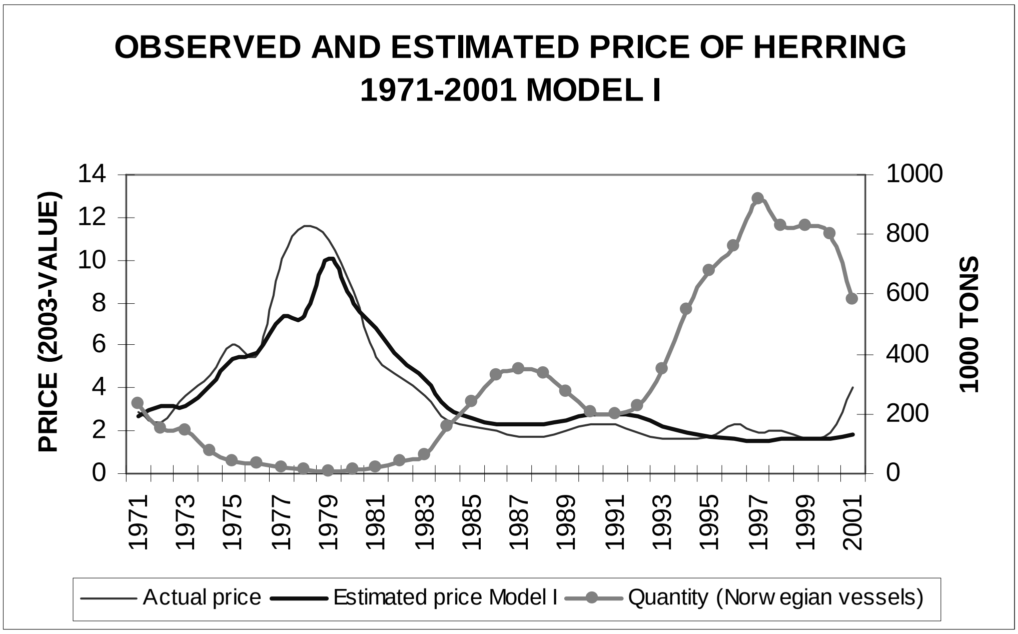

Figure 11: Observed and estimated price and quantity landed of herring

5. REVENUE EFFECTS OF CHANGED LANDINGS

We have assumed that the TAC for herring increases by 25%. Suppose further that all parties involved in sharing the stock also can increase their catches by 25%, i.e. $y_H = 1.25\bar{y}$, given that $\bar{y}$ is the average Norwegian catch during the period 1980-2002. The Norwegian catch will then be

$$y_H^N = 1.25\bar{y}$$

The change in the Norwegian catch is:

$$\Delta_H^N = 0.25\bar{y}$$

During 1908-2001 the yearly average landings of herring were 510 thousand tons. The average landings of herring during 1980-2001 were 396 thousand tons, and 576 thousand tons 1990-2001. Because of the collapse of the herring fishery in the late 1950s and 1960s and the restrictive regulations from the late 1970s to the 1980s, we base the further analysis on data for the period 1990-2001.

The 95% confidence interval for the average landings ($\bar{y}$) is $\bar{y} \pm 1.96\frac{s}{\sqrt{n}}$, where *s* is the sample standard deviation and *n* is the number of observations. Here we get $576 \pm 1.96\frac{268}{\sqrt{12}}$.

Notice that the variance is high. Given the estimated variance, the average aggregated landings of herring will lie in the interval $[425, \quad 729]$. Given that the average catch will increase by about 25% and that the variance will be stable over time, it follows that the future change in the Norwegian catches of herring will lie in the interval $\Delta q \in [106, \quad 182]$ thousand tons. An increase of about 144 thousand tons lies in the middle of the interval.

It is to be expected that climate induced increase in the herring quota will be utilized by the relatively effective purse seine fleet. In the further calculations it is assumed that purse seine vessels with carrying capacity of 8000 hl (744 tons) or more will catch the fish. The economic data for this vessel group is based on the profitability analysis published by the Norwegian Directorate of Fisheries. According to Steinshamn (2005) and engineers at NTNU, the average capacity per vessel is about 15 thousand tons per year.

The climate induced increase in herring catches thus amount to about 7 full time purse seiners according to these figures. It should also be mentioned that the vessels also have quotas for other species which presumably will be affected by global warming.

In the following we will first assume that the change in herring catches does not have any influence on the market price. Secondly we analyse the scenario where the aggregated supply of herring has some influence on the market price. This part of the analysis uses the already presented econometric analyses of the price-quantity relationship.

Infinitely elastic demand

Here we assume that price and quantity can change, but that there is no covariance between price and quantity, i.e. price and quantity fluctuate independently of each other. By using the observed prices for herring landed in Norway by Norwegian vessels during the time span 1990-2001, the average real unit price is estimated to $\overline{p} = 2.11$ kroner per kilo. The standard deviation is $s = 0.65$ and the number of observations is 12. The average price lies in the interval $\overline{p}_H \in [1.74, \quad 2.48]$ kroner per kilo, and the changes in quantity lie in the interval $\Delta q \in [106, \quad 182]$. Given that the changes in unit price are random, the expected change in gross value of the climate induced increase in herring can be expressed as the product of average unit price and expected increase in landed herring, i.e.:

$\Delta R = \overline{p}\Delta q = 2.11x144 \approx 304$ million Norwegian kroner per year

Table 6: Change in revenue
(million Norwegian kroner per year)

		CHANGE IN QUANTITY	
		Low	*High*
Price	*Low*	184	317
	High	265	455

Table 6 combines the interval limits for respectively average price and quantity, and it shows four possible outcomes (extreme points) for the change in gross revenue, given independence between price and quantity. The table shows that the minimum change in revenue is estimated to 184 and the maximum change in revenue is 455 million Norwegian kroner per year. The limits are based on about 2 standard deviations, implying a 97 % probability that the revenue will change inside these bounds.

Elastic demand

The regression analysis above showed that the real price is affected by the quantity landed. In the following the results from the regression analysis are applied to calculate the real price. This price-quantity dependence implies, as we shall see, that the increase in revenue will be less than if the price is independent of the quantity caught.

According to Model I, we have

$$\ln \hat{p}_t = 3.137 - 0.397 \ln q_t$$

where

α : Constant

$\ln \hat{p}_t$: Natural logarithm of price (value of Norwegian landings divided by quantity landed) year $t \in [1970, \quad 2001]$

$\ln q_{1t}$: Natural logarithm of quantity landed (1000 tons) of herring by Norwegian vessels year $t \in [1970, \quad 2001]$

q_F The average landed quantity of herring was 576 thousand tons during 1990-2001. The expected change is 144 thousand tons. Future total landings by Norwegian vessels after the climate change $q_F = 576 + 144 = 720$ thousand tons per year.

These values substituted in *Model I* give the following expected price level *after* the climate has changed and a new expected climate and fisheries-equilibrium is reached:

$$\ln \hat{p}_t = 3.137 - 0.397 \ln q_F$$

$$\ln \hat{p}_t = 3.137 - 0.397 \ln(576 + 144) = 0.525$$
$$\hat{p} = e^{0.525} \approx 1.69$$

The standard error of estimate is $e^{0.262} \approx \pm 1.3$. Notice the high value of the standard error of estimate.

The estimated model II is given by the following expression:

$$\ln \hat{p}_t = 1.614 - 0.202 \ln q_t + 0.476 \ln p_{t-1}$$

The long run part of *Model II* is deduced from the equilibrium where the actual real price is equal the lagged price, i.e.

$$\ln \hat{p} = 3.080 - 0.385 \ln q_F$$

where q_F is the total future landings of herring by Norwegian vessels. The long run price after the climate change is estimated to

$$\ln \hat{p} = 3.080 - 0.385 \ln(576 + 144) = 0.547$$
$$\hat{p} = e^{0.547} \approx 1.73$$

The standard error of estimate is $e^{0.247} \approx \pm 1.28$

The estimated models are also used for calculating the price level *before* the climate change, i.e. the price level given a status quo situation. The average total landings of herring were about 576,000 tons during the period from 1990 to 2001. Substitution into the estimated models gives the following status quo or pre-climate change price level:

Model I:

$$\ln \hat{p}_t = 3.137 - 0.397 \ln(576)$$
$$\hat{p} = e^{0.614} \approx 1.85$$

Model II:

Since we interpolate the price, the short run model has to be applied, i.e. the model $\ln \hat{p}_t = 1.614 - 0.202 \ln q_t + 0.476 \ln p_{t-1}$ is used for calculating the price level before the climate change. The lagged price variable in the model is substituted by the average value for the estimated period less the 1990-observation, i.e. $E(\ln \tilde{p}_{t-1}) = \frac{1}{n} \sum \ln p_{t-1} \approx 0.74$.

$$\ln \hat{p}_t = 1.614 - 0.202 \ln(576) + 0.476 \ln(2.09)$$
$$\hat{p} = e^{0.682} \approx 1.98$$

Table 7: Changes in gross value due to climate changes in the Northeast Atlantic

	MODEL I	**MODEL II**
Calculated price before the climate change	$p_0 \approx 1.90$	$p_0 \approx 1.98$
Expected price after the climate change	$p \approx 1.70$	$p \approx 1.73$
Calculated quantity landed before the climate change	$q_0 = 576$ thousand tons	$q_0 = 576$ thousand tons
Change in quantity	$\Delta q = 144$ thousand tons	$\Delta q = 144$ thousand tons
Change in revenue	$\Delta R = \Delta p q_0 + p_0 \Delta q$ $= (1.70 - 1.90)576 + 1.70(144)$ $= -115 + 245$ $= 130$ million Norwegian kroner	$\Delta R = \Delta p q_0 + p \Delta q$ $= (1.73 - 1.98)576 + 1.73(144)$ $= -144 + 249$ $= 105$ million Norwegian kroner

The climate change is expected to increase the quantity landed in Norway by about 144 thousand tons. The estimated models (inverse demand functions with constant elasticity) take into account how the real price responds to changes in quantity. Table 7 summarizes the effect the changes in price and quantity have on gross revenue.

5. CONCLUSION

It is assumed that the climate change will increase the herring stock by about 25% and, in turn, increase the TAC by the same percent. If the TAC increases by about 25%, it implies that the Norwegian catches can potentially expand by 144 thousand tons per year, given existing distribution formulae for the sharing parties.

The value of the increase in quantity depends on whether the price level of herring is affected by quantity or not. Two scenarios are chosen in order to cover these possibilities; one scenario where price is independent of quantity, and a second scenario where the price is influenced by the quantity landed.

The scenario where price and quantity are independent of each other shows that the average gross revenue will increase by about 300 million Norwegian kroner per year. Because price and quantity change randomly over time, the climate induced increase can fluctuate between the extremes of 180 to 450 million kroner per year. The econometric analyses show on the other hand that there is some dependence between price and quantity. Two models are applied to measure how the climate induced changes in TAC will change the gross revenue in the Norwegian herring fishery. The price-quantity dependent models show that a 144 thousand tons climate induced increase in the Norwegian TAC of herring represents a gross value between 100 and 130 million Norwegian kroner per year.

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