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Climate Change and its Effect on the Norwegian Cod Fishing Industry

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Abstract

The background for the paper is the expected climate change and its effect on the Norwegian cod fishing industry. Global warming is predicted to increase the stock of cod in the Barents Sea. Oceanographers expect that the total allowable catch (TAC) of Northeast Arctic cod will increase by about 50%. The Norwegian part of the TAC is expected to increase by about 100,000 tons, given the existing relative distribution of quota between Russia, Norway and third countries. During the time period from 1990 to 2001 the average total gross value of the Norwegian landed cod was 2.5 billion kroner (2003-value) per year. The climate induced expansion in the cod stock is expected to increase the landed value by the Norwegian fleet by 0.5-1.0 billion Norwegian kroner (2003-value) per year, depending on how sensitive the price is for changes in quantity.

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 cod fisheries. Most of the Norwegian catches of cod derive from the Northeast Arctic stock, which inhabits the Barents Sea and the Norwegian Sea, with only small and dwindling catches coming from the North Sea. Hence the climate changes discussed are the ones expected to occur in 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). The NEZ amounts to about 40% of the total area of the Barents Sea. 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 cod will expand, because of higher temperature and increased supply of zooplankton. The ice-free area would expand towards north and east, and the stock of cod would increase by about 50%. Sundby writes (ibid):

> "*With an ice-free Barents Sea, and an annual mean temperature increase of 1.0 to 1.5 Celsius… the total cod production will increase considerably, probably at least by 50%*".

The catch of cod – totally and for each country – has fluctuated over the years. A climate induced increase of Northeast Arctic cod by about 50% refers to an increase from average catches over the past 10 years.

Even if climate change would increase the stock of cod 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 cod in Norway and in the rest of the Northeast Atlantic. In Section Four we estimate the relation between unit price and quantity landed of cod. Section Five analyses the impact on the revenue in the cod fishery from the expected climate changes. In Section Six we offer some thoughts on the optimal quota for Northeast Arctic cod, even if this is not related to the climate change issue. Section Seven concludes.

2. THE DEMAND FOR COD

The final demand for cod (y_C), or whatever commodity, is determined by the price of cod (p_C), 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 cod is derived from the underlying demand for the commodity which the industry produces. The processing industry's demand for cod as input is a function of the raw fish price of cod, prices of substitutes and complements for cod, and the price of the final product. In the following we are referring to the input demand for cod.

The fisheries for Atlantic cod 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 cod 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 cod is equal to the TAC. Figure 1 shows the initial market equilibrium for cod, i.e. (p_0, y_0)

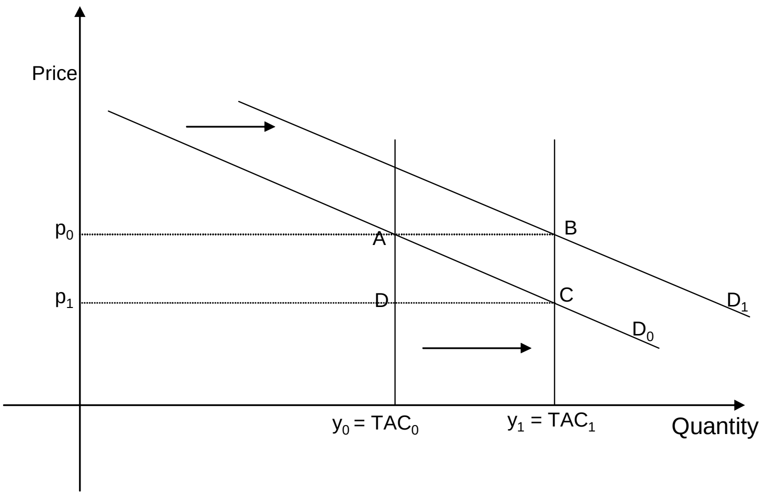


Figure 1: Demand and quota determined supply of cod

If the quota of cod increases from TAC_0 to TAC_1, the supply curve of cod 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 cod. 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 cod at the initial p_0-level, even though the quota and landings of cod have increased. In the following we will ignore these kinds of changes and concentrate on the effects of climate change alone. 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 cod (p_c). 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_c. The climate induced change in gross revenue (ΔR) will then be

$$\Delta R = \Delta y p_c$$

Figure 1 illustrates this scenario, given that the price level of cod 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_c.

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 cod could be affected by an increase in the supply of cod. 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 quota 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 cod, i.e.

$$\varepsilon = \frac{\partial y_c\, p_c}{\partial p_c\, y_c} < 0 .$$

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 cod 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 cod, 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 landed fish 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. On the other hand 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 1977-2001 on the real price of cod, the landed quantity of cod in Norway by Norwegian vessels, the landed quantity of cod in Norway by foreign vessels, and the total catch of cod in the Northeast Atlantic.[1]

3. OVERVIEW OF COD PRICES AND LANDINGS

Figure 2 shows the price and quantity landed of cod in Norway by Norwegian vessels during the period 1977-2001. The Norwegian consumer price index has been used to adjust the price to 2003-value of money.

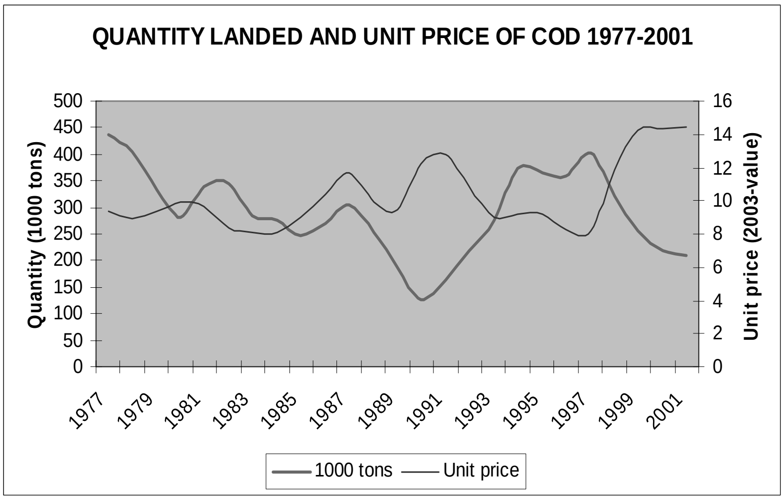
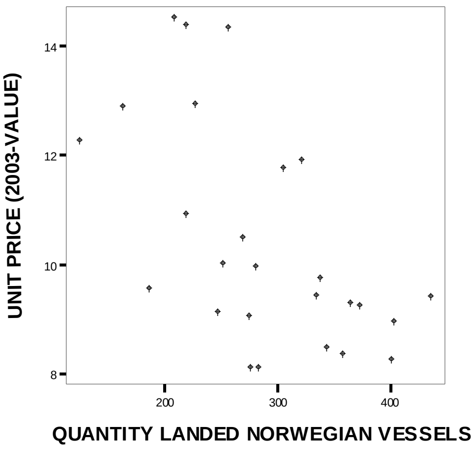


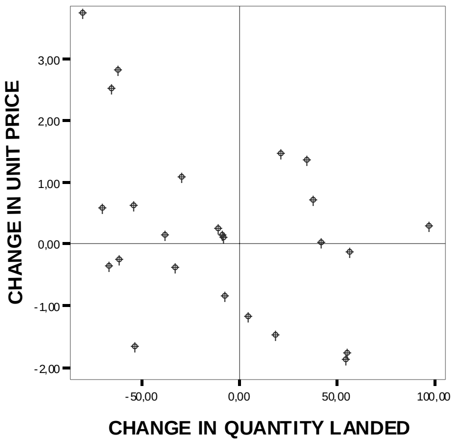
Figure 2: Price on cod and landed quantity in Norwa by Norwegian vessels

Source: Statistics Norway

Figure 2 indicates some tendency to an inverse relationship between price and landings, but there are subperiods where the two have moved in the same direction. Both time series fluctuate without much trend. Figures 3 and 4 further explore the relationship between price and quantity. Figure 3 indicates a negative overall relationship between price and quantity, and Figure 4 that price and quantity change in opposite directions more often than not. In the following we will test whether these relationships are significant or not.

[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.





Figures 3 and 4: Unit price of cod and fish landed by Norwegian vessels 1977-2001

During the 1990s – after the breakdown of the Soviet Union – the landings in Norway by Russian cod trawlers increased dramatically. Cheap Russian cod was mainly bought by the fish processing industry in Finnmark County. Figure 5 shows landed quantity of cod in Norway by Russian trawlers. The figure shows that the landings of cod by the Russian vessels were relatively stable at about 150 thousand tons in the period 1996-2002. It is expected that the landings will decrease in the future because the Russian companies will find more profitable alternatives. During the 2003 and 2004 there was a significant decrease in the landings of Russian vessels in Norway. The decrease in the Russian landings is further discussed below.

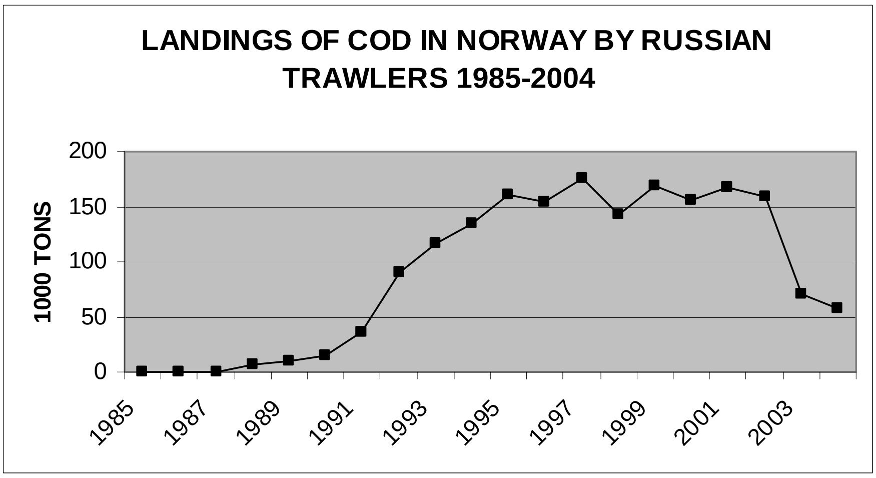


Figure 5: Foreign landings of cod in Norway

Source: Norges Råfisklag

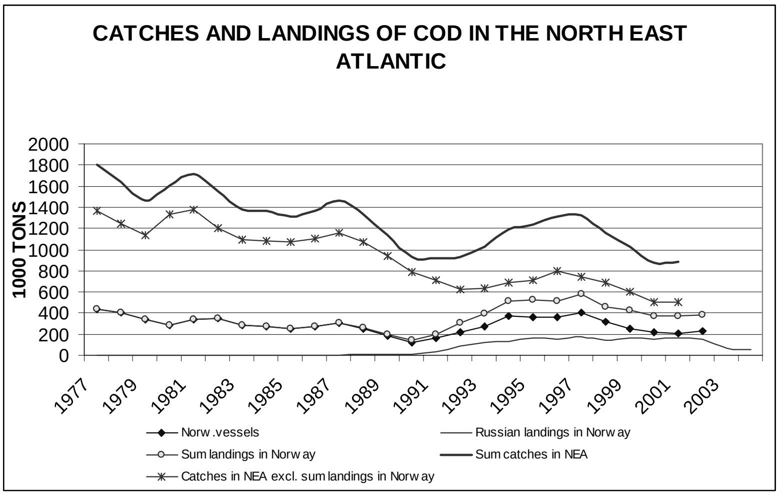


Figure 6: Aggregated catches of cod in the Northeast Atlantic

Source: Statistics Norway and ICES

Figure 6 shows the total catches of cod in the Northeast Atlantic during the period 1977-2001. The total catches have fluctuated, but there is an overall negative trend in the aggregated figures. There was a noteworthy recovery in the period 1990/91-1998, which however was undone in the following years.

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, because the aggregated supply of cod is 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 cod is *not* stable over time. Different functional forms can be used for this purpose, for example double-log, log-linear, or the more flexible Box-Cox-function. We have applied a log-linear functional form.

In a market perspective it is to be expected that Atlantic cod is a relatively homogeneous commodity, and that the price does not depend on whether the fish is caught by, say, Norwegian or Russian vessels. We therefore expect a negative relationship between the unit price of cod realised by the Norwegian vessels and the aggregated supply or catches of cod excluding the landings from Norwegian vessels. The Pearson's correlation matrix shows that there is a negative relation between, respectively, price and quantity landed by Norwegian vessels and price and aggregated catches (excluding landings from Norwegian vessels) in the Northeast Atlantic. There is also a positive covariance between the quantity landed by Norwegian vessels and total catches of cod in the Northeast Atlantic. The low p-values indicate that the H_0-hypothesis, no correlation, is rejected.

Table 1: Pearson's Correlation matrix

		Unit price (p)	Quantity Norwegian vessels (x_1)	Total catches exclusive Norwegian vessels (x_2)
Pearson Correlation	Unit price (p)	1.000	-.574	-.583
	Norw.landings (x_1)	-.574	1.000	.524
	Total catches in NEA (excl. Norw.landings) (x_2)	-.583	.524	1.000
Sig. (1-tailed)	Unit price (p)	.	.001	.001
	Norw.landings (x_1)	.001	.	.004
	Total catches in NEA (excl. Norw.landings) (x_2)	.001	.004	.
N	Unit price (p)	25	25	25
	Norw.landings (x_1)	25	25	25
	Total catches in NEA (excl. Norw.landings) (x_2)	25	25	25

The landings of cod in Norway by Russian vessels were discussed in a previous paragraph. The quantity landed has been far from marginal compared to the Norwegian landings, and so one would expect that the foreign landings would have some influence on the price. Pearson's correlation indicates no significant correlation between the price realized by the Norwegian fishermen and the Russian landings in Norway, i.e. $r = 0.162$ (p=0.260 for a one-tailed test). Figure 7 shows the relation between unit price and Russian landings in Norway. The figure confirms what the correlation coefficient measures.

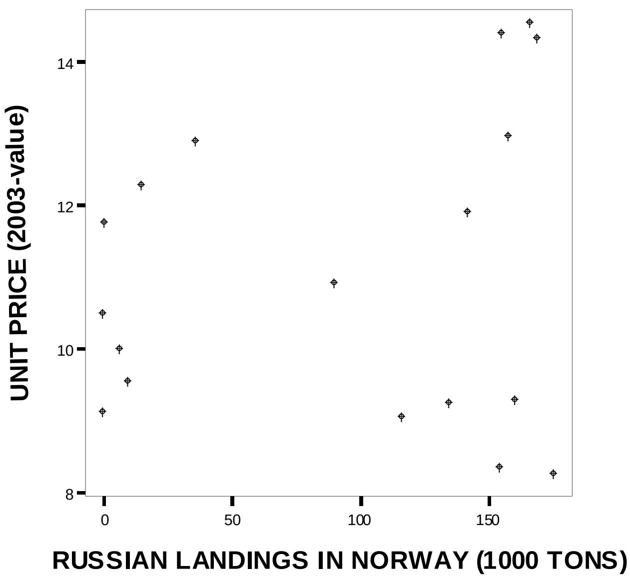


Figure 7: Unit price and foreign landings in Norway

A closer look at the price the Norwegian fish processing industry paid for Norwegian landed cod and Russian landed cod indicates two different price levels, with the Russian trawlers being paid less for their cod compared to the Norwegian ones. A statistical test based on data for the period 1985-2002 confirms a significant difference in price. The following *t*-test operator for differences between means was used.

$$t = \frac{\bar{x}_N - \bar{x}_R - (\mu_N - \mu_R)}{\sqrt{(n_N - 1)s_N^2 + (n_R - 1)s_R^2}} \sqrt{\frac{n_N n_R (n_N + n_R - 2)}{n_N + n_2}}$$

where

Parameters	Definition	2003-value
$\bar{x}_N$	Average real unit price Norwegian landings	11.00
$\bar{x}_R$	Average real unit price Russian landings	8.94
s_N^2	Sample variance Norwegian unit price	4.49
s_R^2	Sample variance Russian unit price	5.62
n_N	Sample number (1985-2001)	18
n_R	Sample number (1985-2001)	18

The model tests whether the means are equal or not, i.e. $H_0 : \mu_N - \mu_R = 0$. If the numbers in the table are substituted into the test-formula, the student's *t*-value is calculated to $t = 2.75$, and with $n_N + n_R - 2$ degrees of freedom and critical values $t^C = \pm 1.697$ (5 %-level two-sided test) the null-hypothesis is rejected. Hence the unit value of the Russian cod in this period is significantly different from the unit value of the Norwegian cod. There are several possible explanations; asymmetric information between Russian and Norwegian fishermen could have enabled the buyers to systematically underbid Russian cod, there could be differences in quality and size between Russian and Norwegian landed cod, and the opportunity cost for the Russians could be lower because of a higher tariff on Russian cod exported to the EU-market. The statistically founded argument that there is no influence on the price of cod from the Russian landings would probably not be valid, however, if the landed quantity would increase sufficiently.

Given the dependence of the price of cod on Norwegian landings and aggregate landings of cod in the Northeast Atlantic area (NEA – see Appendix for a definition), we proceed to estimate demand models. The first model to be estimated is (Model I):

$$\ln p_t = \alpha + \beta_1 \ln x_{1t} + \beta_2 \ln x_{2t} + \varepsilon_t$$

where

α : Constant

$\ln p_t$: Natural logarithm of price (value of Norwegian landings divided by quantity landed) year $t \in [1977, \quad 2001]$

$\ln x_{1t}$: Natural logarithm of quantity landed (1000 tons) of cod by Norwegian vessels year $t \in [1977, \quad 2001]$

$\ln x_{2t}$: Natural logarithm of total catches of cod (1000 tons) in the North Atlantic excluding landings by Norwegian vessels year $t \in [1977, \quad 2001]$

ε_t : Residual year $t \in [1977, \quad 2001]$

The tables below show the results from the estimations.

Table 2: Model Summary

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	
.662	.439	.388	.14376	.439	8.604	2	22	.002	.817

About 40 % of the variation in the price can be explained by the model, and the *F*-value indicates that the hypothesis $H_0 : \beta_1 = \beta_2 = 0$ can be rejected. The value of the Durbin-Watson statistics indicates positive autocorrelation (first order autoregressive pattern). Even though the estimated coefficients are unbiased, autocorrelation leads to inefficient parameter estimates. A typical effect from positive autocorrelation is overestimation of *t*-values and R^2-value. Table 3 summarizes coefficient statistics.

Table 3: Coefficients Model I

Modell	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B		Correlations			Collinearity Statistics	
Coefficients	B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
α	5.762	.898		6.418	.000	3.900	7.623					
$\ln x_1$	-.227	.115	-.370	-1.973	.061	-.466	.012	-.574	-.388	-.315	.725	1.379
$\ln x_2$	-.316	.152	-.389	-2.072	.050	-.632	.000	-.583	-.404	-.331	.725	1.379

The regression gives the following estimated model:

$$\ln \hat{p}_t = 5.762 - 0.227 \ln x_{1t} - 0.316 \ln x_{2t}$$

The estimated coefficients are barely significantly different from zero. VIF-values below 2 indicate no serious multicollinearity between x_1 and x_2. The model predicts that, on average, the real price will reduced by about 0.2 % if landings from Norwegian vessels increase by 1 %, and the price is expected to be reduced by 0.3 % if the total catches in the NEA (excluding

Norwegian catches) increase by 1 %. The total change is about 0.5 % if both x_1 and x_2 increase by 1 %. The estimated own price elasticity is -4.4.

The following alternative model (Model II) was also estimated:

$$\ln p_t = \alpha + \beta_1 \ln q_{1t} + \beta_2 \ln p_{t-1} + \varepsilon_t$$

α : Constant

$\ln p_t$: Natural logarithm of price (value of Norwegian landings divided by quantity landed) year $t \in [1977, \quad 2002]$

$\ln q_t$: Natural logarithm of quantity landed (1000 tons) of cod by Norwegian vessels year $t \in [1977, \quad 2002]$

$\ln p_{t-1}$: Natural logarithm of the lagged unit price $t \in [1977, \quad 2002]$

ε_t : Residual year $t \in [1977, \quad 2002]$

The results from the regression are presented in table 4 and 5.

Table 4: Model II Summary

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	
.790	.625	.590	.12110	.625	18.296	2	22	.000	1.186

The value of $\overline{R}^2 = 0.59$ indicates that this model can explain more of the price variation compared to the model above. The *F*-value is also significantly higher than the critical value. Because the model has a lagged dependent variable as an explanatory variable, the DW-test for autocorrelation must be modified. The following test operator is applied:

$$h = \left[1 - \frac{DW}{2}\right]\sqrt{\frac{T}{1 - T[\mathrm{var}(\beta_2)]}}$$

The formula gives the value $h = 3.16$, which is higher than the critical value $h^C = 1.645$ (5 % level) for the hypothesis of *no* first order positive serial correlation. Table 5 presents the coefficient statistics.

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	1.994	.783		2.548	.018	.371	3.618					
Lnq_t	-.197	.098	-.299	-2.011	.057	-.400	.006	-.586	-.394	-.263	.773	1.294
Laglnprice	.621	.153	.603	4.057	.001	.303	.938	.745	.654	.530	.773	1.294

The estimated model (Model II) is

$$\ln \hat{p}_t = 1.994 - 0.197 \ln q_{1t} + 0.621 \ln p_{t-1}$$

The coefficient for landed quantity is significantly different from zero and the sign is consistent with economic theory. VIF-value is below 2 and it indicates no multicollinearity between the independent variables. The model predicts that the unit price will fall by about 0.2 % if the quantity landed from the Norwegian vessels increased by 1 %. The short run own price elasticity is -5.08. The long run inverse demand elasticity is $\frac{\beta_1}{1-\beta_2} \approx -0.52$, i.e. the long run demand elasticity is -1.924. The *long run* relation between real unit price and landed cod by the Norwegian vessels can be expressed in the following way:

$$\ln \hat{p} = 5.26 - 0.519 \ln q$$

Figure 8 shows actual and estimated unit price with the use of Model I and II and the long run version of Model II. Figure 9 plots the 95 % confidence interval for the estimated mean unit price.

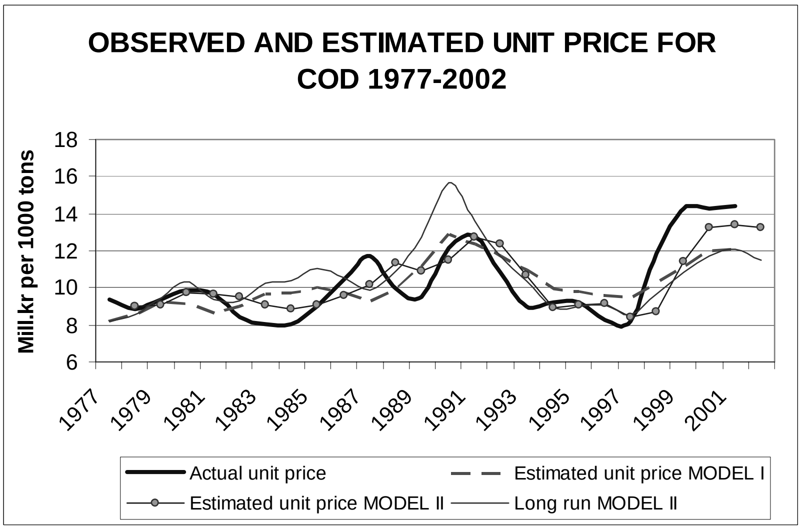


Figure 8: Observed and estimated price on cod

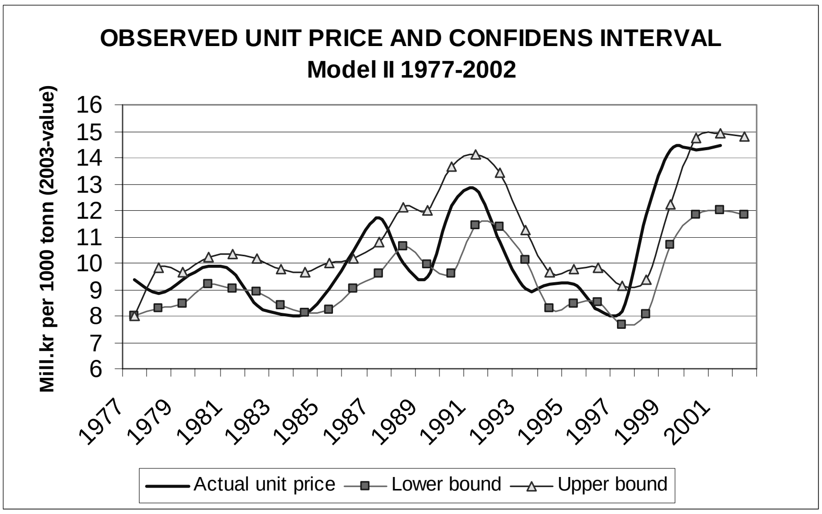


Figure 9: Observed price and confidence interval

5. REVENUE EFFECTS OF CHANGED LANDINGS

The TAC of the Northeast Artic cod is shared by Norway, Russia and some third countries. The third countries' share has increased during the period 1977-2003, but the last four years the share has stabilized at about 14% of the TAC. The rest is shared 50-50 by Russia and Norway. Denoting the TAC of the cod by y_C , the combined quotas of Russia and Norway are $y_C(1-1.14)$. We also assume that the landings reflect the TAC. The main climate induced changes are expected to take place in the northern part of Northeast Atlantic, and so the calculation of the future quotas does not take into account the Norwegian coastal cod fishery. On the other hand the analyses of the expected future real price of cod do take into account the landings of coastal cod. The argument is that coastal cod and Arctic cod are perfect substitutes and the fish is caught at the same time of year.

It is difficult to predict whether the spawning area of the cod will change in the future; for example, whether new spawning areas will become established on the coast of the Kola Peninsula and along Novaya Semlya. It should be mentioned that if the spawning area and the migration pattern change, the distribution of the TAC between Norway and Russia and third countries could also change. Here we assume no changes in the distribution between the parties. Climate induced changes in the distribution of quotas of the Northeast Arctic cod between Norway and Russia are discussed by Hannesson (2004).

Suppose, as discussed earlier, that the TAC of Northeast Arctic cod increases by 50%, i.e., $y_T = 1.5\bar{y}$, where $\bar{y}$ is the average total catch during the period 1986-2003. The Norwegian share of the future catch, according to the above mentioned distribution, would be:

$$y_N = (1-0.14)(0.50)1.5\bar{y}$$

Hence the change in the Norwegian catch of cod would be

$$\Delta_N = (1-0.14)(0.50)1.5\bar{y} - (1-0.14)(0.50)\bar{y}$$
$$= \bar{y}(1-0.14)(0.50)0.5 \approx 0.22\bar{y}$$

The aggregated average landings of Northeast Arctic cod $(\bar{y})$ were calculated to 483,000 tons during 1977-2003 (Aglen, 2004). During the time span from 1908 to 2001 the yearly average Norwegian landings of cod were 231,000 tons (including coastal cod). The time period 1986-2003 is chosen as a valid reference period because there exist bargaining protocols between Norway and Russia (ibid).The average Norwegian landings of Northeast Arctic cod (excluding catches of Norwegian coastal cod) amounted to about 227,000 tons during the period 1986-2003 (ibid). The aggregated average catches were 493,000 tons in the referred period (ibid). In the remaining part of the analysis we will use data from the period 1986-2001. The Norwegian coastal cod amounts to about 40,000 tons landed fish per year during the last 10 years. Hence the future Norwegian level of catches with global warming may be

$$y_N = (1-0.14)(0.50)1.5(493) = 318{,}000 \text{ tons}$$

The average aggregated TAC and catches are associated with uncertainty. 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, in this case $493 \pm 1.96\frac{171}{\sqrt{18}}$. Given that the landings in the period 1986-2003 reflect a relatively stable situation with constant variance, the average actual landings of cod are expected to lie in the interval $y \in [414, \;\; 572]$ thousand tons, with 493 thousand tons in the middle of the interval. The climate change during a 50 years time span is expected to push the system out of a presupposed equilibrium, so that the Norwegian catches of Northeast Arctic cod would increase by 22 % of the present average TAC, as shown above. Hence the average *increase* in the Norwegian catches of cod is estimated to:

$$\Delta_N = 0.22\bar{y} = 0.22(493) \approx 108{,}000 \;\text{ tons}$$

Given that the variance of the catch is *not* changed during these years, it follows that the future *change* in the Norwegian catches of cod will, compared to the last 18 years average, lie in the closed interval: $\Delta_N \in [91, \;\; 126]$ thousand tons. An increase of about 108 thousand tons lies in the middle of the interval.

What, then, is the economic value of the Norwegian part of the increase in TAC? The net value depends on the future market price on cod and the costs of catching the fish. Furthermore, the broader economic impact of the potential increase in the catch of cod depends on whether the fish is caught by the coastal fleet or by the trawlers, processed on board or in land based facilities, or landed in Norway or exported directly to markets abroad.

It is to be expected that the climate induced increase in the quota will be utilized mainly by the trawler fleet. Since the increase in the cod stock will be concentrated further north and east in the Barents Sea, it will not be possible for the coastal fleet to catch this fish due to distance. This will have to be done with cod trawlers, for example vessels which are about 250 gross register ton with on-board processing lines. The cod quota is assumed to *increase* by about

100,000 tons on the average per year. According to Steinshamn (2004) and engineers at NTNU, these trawlers can catch about 5,000 tons per year.

The climate induced increase in cod catches thus amount to about 20 full time cod trawlers according to these figures. It should also be mentioned that the vessels also catch other fish and have quotas for other species than cod. It is not unrealistic to expect that the biomass and TAC will increase also for other cod-like species (haddock, saithe, and others), but this will not be further pursued here.

In the following we will first assume that the aggregated change in landed cod does not have any influence on the market price. Secondly we analyse the scenario where the aggregated supply of cod 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

By using the observed prices for Northeast Arctic cod and coastal cod landed in Norway by Norwegian vessels during this time span 1986-2001, the average real price is estimated to $\overline{p} \approx 11$ kroner per kilo. The standard deviation is $s = 2.09$ and the number of observations is 16. The average unit price (2003-value) lies in the closed interval $\overline{p} \in [10, \quad 12]$ kroner per kilo. Given that the changes in unit price are random, the expected change in gross value of the climate induced increase in cod can be expressed as the product of average unit price and expected increase in landed cod, i.e.:

$\Delta R = \overline{p}\Delta q = 11x108 \approx 1188$ million Norwegian kroner per year

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 dependency 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

$$\ln \hat{p}_t = 5.762 - 0.227 \ln x_{1t} - 0.316 \ln x_{2t}$$

where

α: Constant

$\ln \hat{p}_t$: Natural logarithm of price (value of Norwegian landings divided by quantity landed) year $t \in [1977, \quad 2001]$

$\ln x_{1t}$: Natural logarithm of quantity landed (1000 tons) of cod by Norwegian vessels year $t \in [1977, \quad 2001]$

$\ln x_{2t}$: Natural logarithm of total catches of cod (1000 tons) in the Northeast Atlantic (NEA) *exclusive* landings by Norwegian vessels year $t \in [1977, \quad 2001]$

x_1: 375,000 tons landed *after* the climate change The landed quantity includes 40,000 tons Norwegian coastal cod, i.e. 227,000 + 108,000 + 40,000 = 375,000 tons. Average landed cod *before* the climate change $x_1^0 \approx 269{,}000$ tons and it includes 40,000 tons Norwegian coastal cod.

x_2: 1013,000 tons North Atlantic cod caught fish *after* the climate change. The number presupposes no changes in catches in ICES areas *outside* areas I, IIa and IIb, i.e. the average was 609,000 thousand tons during 1986-2001. The future catches in ICES areas I, IIa and IIb are estimated to 404,000 tons excluded the Norwegian part of it, i.e. 335,000 tons. Caught fish in the North Atlantic *before* the climate change: $x_2^0 \approx 862{,}000$ tons.

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

$$\ln \hat{p}_t = 5,762 - 0.227 \ln(40+335) - 0.316 \ln(609+404) = 2.231$$

$$\hat{p} = e^{2.231} \approx 9.30$$

The standard error of estimate is $e^{0.144} \approx \pm 1.15$

The estimation of the long run part of *Model II* gave the following result:

$$\ln \hat{p} = 5.26 - 0.519 \ln q$$

where q is the total landings of cod by Norwegian vessels. The long run price after the climate change is estimated to

$$\ln \hat{p} = 5.26 - 0.519 \ln(40+335) = 2.18$$

$$\hat{p} = e^{2.18} \approx 8.88 \approx 8.90$$

The standard error of estimate is $e^{0.121} \approx \pm 1.13$

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 cod were about 269,000 tons during the 1986-2001 period, and the average total catches of cod in the North Atlantic was about 862,000 tons. Substitution into the estimated models gives the following status quo or pre-climate change price level:

Model I:

$$\ln \hat{p}_t = 5.762 - 0.227\ln(269) - 0.316\ln(862) = 2.356$$
$$\hat{p} = e^{2.356} \approx 10.55 \approx 10.6$$

Model II:

Since we interpolate the price, the short run model has to be applied, i.e. the model $\ln \hat{p}_t = 1.994 - 0.197\ln q_{1t} + 0.621\ln p_{t-1}$ 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 1986-observation, i.e. $E(\ln \tilde{p}_{t-1}) = \frac{1}{n}\sum \ln p_{t-1} \approx 2.41$.

$$\ln \hat{p} = 1.994 - 0.197\ln(269) + 0.621\ln(11.17) = 2.388$$
$$\hat{p} = e^{2.388} = 10.89 \approx 11$$

The climate change is expected to increase the quantity landed in Norway by about 100 thousand tons. The estimated models (inverse demand functions with constant elasticity) take into account how the real price responds to changes in quantity. Table 6 summarizes the economic effect the changes in price and quantity has on gross revenue.

Table 6: Changes in gross value due to climate changes in the Northeast Atlantic

	MODEL I	**MODEL II**
Calculated price before the climate change	$p_0 \approx 10.6$	$p_0 \approx 10.9$
Expected price after the climate change	$p \approx 9.3$	$p \approx 9$
Calculated quantity landed before the climate change	$q_0 = 269$	$q_0 = 269$
Change in quantity	$\Delta q = 108$ thousand tons	$\Delta q = 108$ thousand tons
Change in revenue	$\Delta R = \Delta p q_0 + p\Delta q$ $= (9.3 - 10.6)269 + 9.3(108)$ $= -350 + 1004$ $= 654$ million Norwegian kroner	$\Delta R = \Delta p q_0 + p\Delta q$ $= (9 - 10.9)269 + 9(108)$ $= -511 + 972$ $= 461$ million Norwegian kroner

6. QUANTITY-DEPENDENT PRICE AND OPTIMAL QUOTAS

After the climate change, the total catch by the Norwegian fleet is expected to average about 312 thousand tons per year. It should be mentioned that this is not necessarily the *optimal* quota which maximizes the economic rent in the fishery. Both of the models that were estimated show that the real price is sensitive to changes in the aggregated landings of cod – even though each individual fishing firm is too small to affect the price. This price-quantity relationship must be taken into account when choosing the optimal TAC-level, provided it is derived from the export markets for the final products. Letting the quota be determined by equality between the marginal revenue and the marginal cost of fishing would not maximize consumer surplus, but this accrues to foreign consumers and is of no interest for the Norwegian economy. Hence it would make sense to set the quota no higher than that which would maximize the total revenue. In years when the fish stock does not permit this, the quota would have to be set lower. If, on the other hand, the downward-sloping demand for raw fish is due to rising costs in the processing industry, setting marginal revenue equal to marginal cost would not be consistent with maximizing producer surplus, but the latter quantity is of course a benefit for the Norwegian economy.

The fact that the price was shown to depend on the total landings of cod from the Northeast Atlantic and that landings in Norway from Russian trawlers had no significant effect on the price indicates that the downward sloping demand for raw fish is due to the export markets. Figure 10 illustrates the point about optimal quota in this case. The figure shows the aggregated inverse demand curve for cod (Model II), the marginal revenue curve, and three horizontal curves which map the marginal cost of catching the cod.

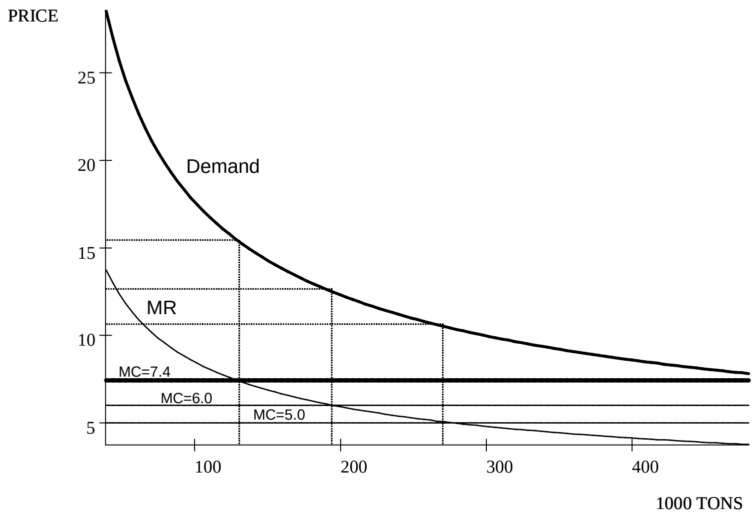


Figure 10: Model II – demand for cod

Figure 10 shows that the economic rent and the optimal quota depend on the marginal cost of fishing the cod. In the long run it is expected that there will be no capacity limitations, and it is arguable that one should apply constant returns to scale when analyzing how much more cod should be caught in the future. If the long run marginal cost (MC) is 7.4 Norwegian kroner, then the optimal quota would be 130 thousand tons, and if the marginal cost is 5 Norwegian kroner the optimal, the profit maximizing quota would be about 280 thousand tons. The optimal profit decision does not take into account what actually is bioeconomically optimal. Steinshamn (2005) has estimated the *variable* cost for cod trawlers to about 5.5. It appears reasonable, therefore, to assume that the marginal costs are between 5 and 6. The model is obviously very sensitive to the level of the marginal cost.

7. CONCLUSION

The expected warming of the Barents Sea could increase the Norwegian catches of cod in this area by about 100,000 tonnes per year. The resulting increase in gross value could exceed one billion kroner per year, but could be a lot less because of an adverse effect on prices in foreign markets; the revenue increase could be only half of this or less. Needless to say, fishing costs would also rise, but probably in proportion to catches, as new boats of an optimal design could be built for this. The boats needed would be ocean going trawlers, because the increase in the stock is expected to happen in areas far from the Norwegian coast.

It is in fact quite possible that this increase in catches would be of limited or no value to the Norwegian economy if the effect on prices in foreign markets is taken into account. In the past 20 years or so, the Norwegian catches of cod have been about 270,000 tonnes per year, and would be expected to increase to about 370,000 tonnes per year. If this higher quota were worthwhile, the marginal cost of fishing would have to be lower than 5 kroner per kg. (see Figure 10), which is less than estimated by Steinshamn (2005). In needs to be emphasized, however, that the sensitivity of the price to changes in landings could be overestimated, in which case the new and higher quota would be worthwhile at a higher cost of fishing.

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APPENDIX

The Northeast Atlantic (NEA) includes the following ICES-areas:

I	Barents Sea
IIa	Norwegian Sea
IIb	Spitzbergen Bear Island
IIIa	Kattegat and Skagerak
IIIb,c	The Sound and Belt Sea
IIId	Baltic
IVa	North Sea North
IVb	North Sea Central
IVc	North Sea South
Va	Iceland grounds
Vb_1	Faroe Plateau
Vb_2	Faroe Bank
VIa	NW. coast Scotland N.Irland
VIb	Rockall
VIIa	Irish Sea
VIIb,c	W.coast Ireland Porcupine Bank
VIId,e	English Channel East and West
VIIf	Bristol Channel
VIIg-k	S.coast Ireland
VIIIa-e	Bay of Biscay
IXa,b	Portuguese waters
XIV	East Greenland