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Harvest Functions:
The Norwegian Bottom Trawl Cod Fisheries

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Abstract *A detailed and comprehensive set of catch and effort data for the cod fisheries of 18 Norwegian bottom trawlers have been obtained for the period 1971–85, a period with few binding quota restrictions on vessel operations. Harvest functions have been designed and estimated. The independent variables are hours of trawling per vessel day and biomass of the cod stock (3+). Daily biomass estimates have been calculated by polynomial interpolation of the annual estimates of the International Council for the Exploration of the Sea (ICES). By maximizing the log-likelihood function using numerical methods, parameter estimates and performance indicators of the different models were obtained. The best result was obtained for a harvest model allowing for seasonal changes and with an autocorrelated error term. For this model, the stock-output elasticity is estimated at 0.424, the effort-output elasticity at 1.232, and the technological change at about a 2% annual increase in productivity. The seasonal changes in catchability are significant, with the lowest intra-annual catchability being less than 30% of the annual maximum.*

Key words Harvest functions, bioeconomics, production theory, cod, bottom trawl fisheries.

JEL Classification Codes D24, O13, Q21, Q22.

Introduction

Man's effort and nature's fish stocks produce fish harvest. An intriguing question that for long has occupied the minds of fishers, fisheries biologists, and fisheries economists is to what extent effort and stock size affect catch rates. The fishing mortality rate has been the focus of modern science-based fisheries management. A number of applied studies has been carried out, analysing the short- and long-term effects on stocks, using fishing mortality as the control variable. Fisheries biologists, in particular, tend to use this control, whereas economists mostly use fishing

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effort. Surprisingly, few studies on the relationship between fishing mortality and fishing effort have been carried out. Harvest functions, with effort and stock as the (short-term) independent variables and harvest rate as the dependent variable, contribute to bridging the gap between mortality and effort. This paper is a contribution to the literature in this field, using catch, effort, and stock biomass data for a Norwegian bottom trawl cod fishery to estimate harvest functions.

To study how catch depends on effort and stock, a detailed and comprehensive set of catch and effort data for the cod fisheries of 18 Norwegian bottom trawlers has been obtained for the period 1971–85. Catch and effort data prior to 1971 were not available in the database used. The year 1985 was chosen as the cut-off year to avoid data from later years when quota restrictions became binding on vessel operations. Cod vessel-group quotas for trawlers were introduced in 1976, one year before the introduction of the Norwegian Exclusive Economic Zone (EEZ), and individual trawler quotas for cod commenced in 1982. However, having considered the way regulations were implemented, including the use of (generous) autumn quotas, we have concluded to use 1985 as the cut-off year. Actually, restrictions on trawler investment and operation have a long tradition in Norway where limited entry (licenses) was introduced in 1938. Technical regulations (*e.g.*, vessel and gear specifications, area, and seasonal closure) have been in place for decades, but changes to such regulations during the period of investigation are not considered great enough to hamper the results. Thus, for 1971–85 catch and effort data are considered as if there were no binding quota restrictions on vessel operations and no change of technical regulations.

In this paper, harvest functions have been designed and estimated. In line with the literature in this field, the independent variables are hours of trawling (per vessel day) and exploitable biomass of the cod stock. The unit of time is one day, and the independent variable is catch per hour of trawling. Daily biomass estimates have been calculated by polynomial interpolation of the annual 1 January estimates of the International Council for the Exploration of the Sea (ICES). By maximizing the log-likelihood function by numerical methods, parameter estimates and performance indicators of the different models were obtained. Several models were tested (see Skjold 2001), and this paper presents those that are most robust from a statistical point of view.

The paper is organized as follows. The next section provides some background information on harvest functions and their use, as well as some references to the literature in this field. Thereafter, the Data section describes data and data sources used. The Model section presents and discusses model equations to be estimated. This includes an intra-annual seasonality term and an error term to cover development unexplained by the regular variables. Estimation findings are presented in the Results section and examined in the immediate following Discussion section. Finally, a brief summary of the paper is presented in the Conclusion section, together with some ideas for further work.

Background

The Schaefer harvest function (Schaefer 1957),

$$h(E, W) = qEW, \tag{1}$$

is commonly used in bioeconomic studies, assuming a bi-linear relationship between the two inputs, *fishing effort* (E) and *stock biomass* (W), and the produced *catch* (h). The coefficient q is a gear and stock specific constant, referred to as the catchability coefficient.

In empirical stock assessment models, fishing mortality, F, is often assumed to be proportional to fishing effort, E:

$$F = qE. \tag{2}$$

As seen from equation (1), *catch per unit effort* (CPUE) is proportional to the *stock biomass*, and *catch per unit biomass* is proportional to *fishing effort*. The Schaefer harvest function implies that an increase in stock biomass leads to an increase in the catch at the same rate, for a fixed fishing effort. The underlying assumptions are that the fish stock is homogeneously distributed in the sea and that the fishing gear catches with a given selectivity pattern. The relationship between fishing mortality and fishing effort in equation (2) is equivalent to using the Schaefer harvest function, equation (1). This is, in fact, an often-used assumption for the tuning of Virtual Population Analysis (VPA) models used by Regional Fisheries Organisations (RFOs) (see Anon. 2001).

The more general Cobb-Douglas production function has been used in some empirical works on Northeast Arctic cod harvest (Hannesson 1983; Flaaten 1987). Other functional forms and non-parametric methods have also been used to analyse technical efficiency and stock dependency of fisheries (see Coglan, Pascoe, and Mardle 1998; Kirkley, Squires, and Strand 1995). The Cobb-Douglas function involves two additional parameters compared to equation (1):

$$h(E, W) = qE^{\alpha}W^{\beta}. \tag{3}$$

The additional parameters are the effort-output elasticity (α) and the stock-output elasticity (β). Parameters α and β gives the percentage increase of *catch* (h) with an increase of 1% of *fishing effort* (E) and *stock biomass* (W), respectively. The special cases of $\alpha = \beta = 1$ restores the Schaefer equation (1). *A priori* for cod fisheries one would expect the elasticities to be within the ranges:

$$\alpha \geq 0$$

$$0 \leq \beta \leq 1.$$

The findings of Hannesson (1983) (covering the period 1971–78) and Flaaten (1987) (covering the period 1971–85, as in this study) do not contradict these presumptions. The α-values found in both studies vary substantially across models, but with low levels of significance, while the β-values indicate some gear-specific differences. Active gears, like bottom trawls, which move on the bottom when fishing, and gears that attract fish by bait (long line and hand line), tend to have a lower value of β than other gears. For example, gill nets seem to have β-values closer to 1, which means that the CPUE is almost proportional to the density of fish.

Data

Catch data have been obtained from the Norwegian Directorate of Fisheries, and include daily catches of 18 trawlers for the period 1971–85; altogether 37,748 observations. The database also contains information on vessel size and age, catch area, *etc.* The 18 trawlers were selected from a larger group, using the criteria that they should have *at least one catch registration each year during the period 1971–85.* Recall the arguments, above, for the choice of this particular time period. A graphical presentation of the database and some key numbers are shown in table 1 and figures 1 and 2.

Table 1
Average Day Catch During the Investigated Period, 1971–85, in Tons

Trawler No.	1st Quarter		2nd Quarter		3rd Quarter		4th Quarter	
1	9.65	(7.45)	9.24	(8.80)	6.28	(5.52)	5.02	(4.35)
2	8.39	(6.55)	7.16	(6.86)	4.60	(5.24)	4.71	(3.90)
3	8.38	(6.42)	7.65	(7.34)	4.02	(3.25)	4.44	(4.09)
4	8.20	(6.27)	6.53	(5.99)	4.81	(3.89)	4.33	(3.09)
5	8.42	(6.53)	7.67	(6.71)	4.74	(4.82)	5.62	(4.42)
6	7.78	(6.32)	5.77	(5.55)	4.15	(4.74)	3.77	(3.91)
7	8.91	(7.12)	8.78	(8.12)	5.18	(4.78)	5.58	(5.32)
8	7.90	(6.56)	6.73	(6.00)	4.00	(4.49)	3.52	(3.44)
9	9.19	(6.01)	7.12	(6.45)	4.94	(3.88)	5.20	(3.76)
10	0.93	(0.64)	3.22	(2.08)	1.32	(1.59)	0.58	(0.66)
11	13.07	(10.13)	13.39	(10.72)	7.85	(7.31)	10.10	(12.07)
12	8.16	(6.67)	8.36	(7.29)	3.80	(3.86)	4.10	(3.72)
13	9.68	(6.69)	8.89	(6.71)	7.77	(7.52)	6.20	(4.85)
14	7.85	(6.65)	7.06	(7.71)	4.19	(4.98)	3.30	(4.10)
15	13.10	(9.39)	12.72	(10.07)	8.44	(7.15)	8.24	(6.02)
16	12.44	(10.79)	13.10	(14.26)	7.00	(7.34)	8.31	(7.44)
17	13.22	(11.15)	15.33	(12.26)	9.31	(8.87)	9.25	(8.34)
18	-	-	4.22	(3.08)	3.32	(2.57)	-	-

Note: Trawler catches included in the analysis. Standard deviation of day catches of each trawler in parentheses, distributed on quarters of a year.

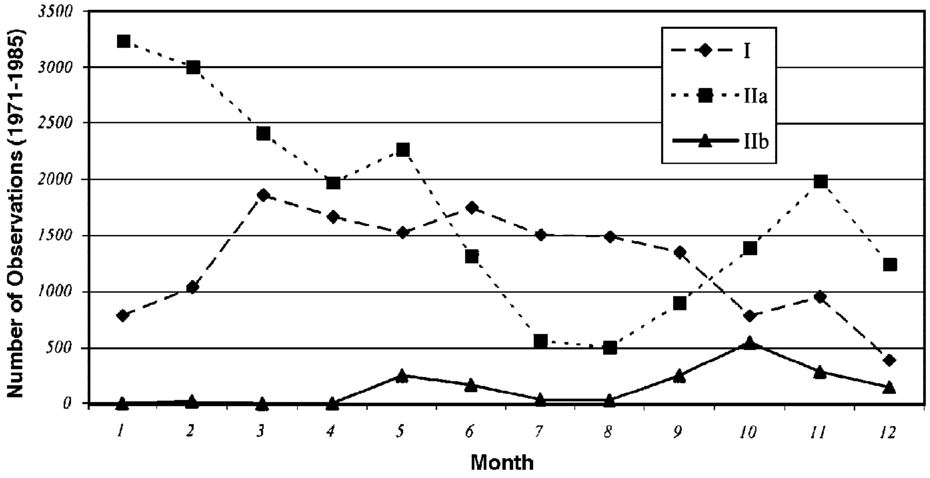

Figure 1. Number of Observations
Number of trawl hauls in the database of the 18 vessels, during the period 1971–85 in ICES areas I, IIa, and IIb, distributed on month number.

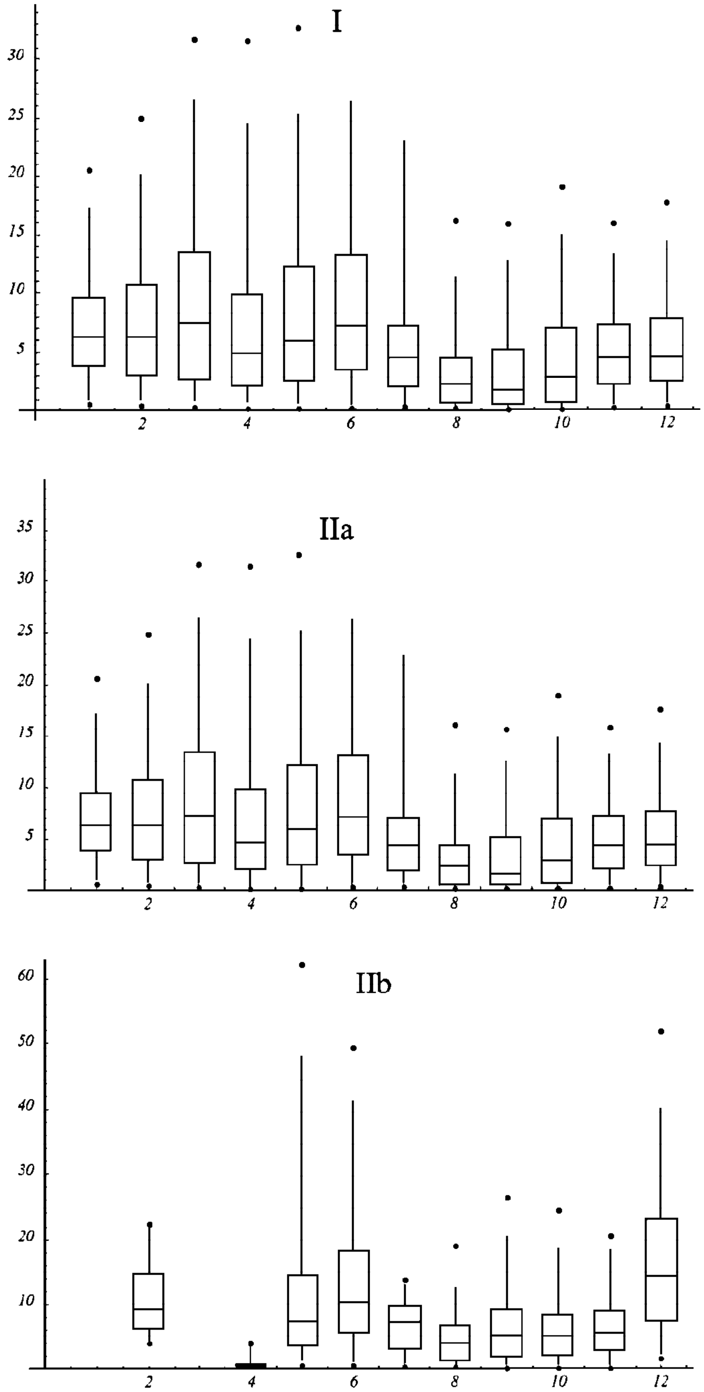

Figure 2. Vessel Catches
Box plots of vessel catch (tons per day) in ICES area I, IIa, and IIb of the 18 vessels grouped monthly (1–12) over the period 1971–85. Ranges used in the box plots are 50 (box with median), 75 (bars), and 95 (points).

With a database of this size, almost 38,000 observations, a thorough quality control of the data is difficult and time consuming. Nevertheless, some obvious faults and mistakes have been found, and data of the following kind has been removed from the material: *catches on non-existent days* (*e.g.*, 32 January and 30 February), *catches lacking registration of trawling hours* (*i.e.*, effort data), *catches of less than 10 kg and more than 100 tons a day from one vessel* (*i.e.*, extremely unlikely data and physically impossible data).

Biomass estimates of the Northeast Arctic cod stock, obtained from the ICES Arctic Fisheries Working Group (Anon. 1994), have been used in this study. The ICES biomass estimates are separated by cohorts (year classes from ages between 3 and 15, inclusive, and older) and refer to 1 January of each year. In order to match the daily catch and effort data of this study, daily biomass data were needed. To obtain daily biomass estimates for the period of investigation, an interpolation method was applied for each cohort; interpolating polynomials of order 3. The results of the interpolations are presented graphically in an aggregated form in figure 3. At the beginning of each year, a new cohort of three-year-old cod is added on top of the others. The development of this cohort biomass is shown as the gap between the cohort line and the line immediately below. Each gap typically widens for a few years, until the cohort reaches its maximum weight and then narrows until it reaches its lowest weight at the age of 15^+. In this study, only the per-day total biomass of all cohorts has been used (for reasons explained below).

The database does not contain any information on the catch distribution on year classes or size groups of the stock, and for this reason this study had to be carried out using the vessels' total daily catches of cod.[1] Based on biological knowledge of the schooling habits among young cod, one could *a priori* expect to find age-specific β-values. However, estimation of age-specific βs has not been possible due to lack of data. The β-values found in this paper should, therefore, be interpreted as weighted averages of the β-values of each year class.

Model

For the purpose of this paper, several production functions for analysing the relationship between *produced catch* and *fishing effort* and *stock biomass* have been tested statistically, including additive production functions. However, additive production functions have been rejected due to errors like negative catch (predictions). Statistically, the Cobb-Douglas functions showed the best performance, and families of eight Cobb-Douglas functions are presented in this paper. They all follow the general form of equation (3), but with two refinements — a seasonal term and a trend term.

A priori we would expect that seasonal fluctuations during a year have an influence on the catchability coefficient, q. Such seasonal fluctuations are likely to be repeated each year. To take these fluctuations into account, an index, s, has been used in the data analyses:

$$s = \frac{\text{day number within a year}}{\text{total number of days of a year}}, \quad 0 < s \leq 1.$$

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[1] Some effort has been put forth to estimate the cod catches distributed on year classes, based on the corresponding age distribution of total annual catches. However, the great seasonal changes within each year make such an indirect estimation very difficult, and the attempts confirmed that the data available were not sufficient for this kind of analysis.

Figure 3. Biomass Estimate of Northeast Arctic Cod
Estimated total biomass of Northeast Arctic cod 1970–85 separated on year classes. The aggregate biomass changes over time as new year classes are added (on top) and biomasses of older year classes change. Biomass changes have been calculated by polynomial interpolations (order 3) of annual biomass estimates on year classes obtained from Anon. (1994) for the period 1970–85.

Thus, the catchability coefficient is a function of the season index, symbolized as $q(s)$.

The trend terms of the statistical analysis of Hannesson (1983) and Flaaten (1987) were considered mainly to reflect technological improvement of the fisheries during the investigated period. Following this approach, we include an exponential trend term, with γ, in the production function. Thus, γ expresses the annual percentage neutral technological change. The expanded C-D harvest function is:

$$h(s,t,E,W) = q(s) \quad e^{\gamma t} \quad E^{\alpha} \quad W^{\beta}. \tag{4}$$

To allow for flexibility of seasonal changes, the catchability term, $q(s)$, is assumed to be a general sine function:

$$q(s) = e^{\left[k_1 + k_2 \sin(k_3 \, s) + k_4 \cos(k_5 \, s)\right]}, \tag{5}$$

which includes five parameters, k_j, $j \quad (1,5)$. This allows the harvest model of equation (4) to correct for pure seasonal changes that cannot be explained by the two independent variables E and W. Possible causes of these fluctuations include changes of cod density in different areas due to a normal migration pattern.

For computational purposes, the catchability term may be expressed as the log catchability term:

$$\log\left[q(s)\right] = k_1 + k_2 \quad \sin(k_3 \quad s) + k_4 \quad \cos(k_5 \quad s). \tag{6}$$

Statistical analyses are carried out by maximizing the log-likelihood function of the harvest equation:

$$\hat{h}_i(s, t, E_i, W_i) = q(s) \quad e^{\gamma t} \quad E_i^{\alpha} \quad W_i^{\beta} \quad e^{u_i}, \tag{7}$$

where t indicates year and i indicates observation number; $i = (t - 1970)$, s [1, 37748]. Catch quantity (h) and stock biomass (W) are measured in tons per day and tons, respectively, while fishing effort (E) is measured in trawl hours per day. Thus, catch and effort are flow concepts, whereas biomass is a stock concept.

The error term, u_i, is expected to follow an autoregressive process of first order and is defined by:

$$\begin{aligned} \log(u_i) &= \varphi \log(u_{i-1}) + v_i \\ v_i &\sim N(0, \sigma^2) \end{aligned} \tag{8}$$

with a constant φ. The intuition behind a 1.order-autoregressive process is that the unexplained catch today mainly depends on yesterday's fishing conditions. A reason for autocorrelation in the error term is factors not included in the model, such as fish migration or weather conditions. In the models presented here, unexplained catch today also depends on yesterday's catch; *i.e.*, equipment used, fishing area, and *other* conditions yesterday.

Parameters have been estimated for eight models. The distinction between the different models is whether the error term follows a 1.order autoregressive process ($\varphi \neq 0$) or not, whether the catchability coefficient has seasonal variation or not ($k_2 = k_4 = 0$ for no seasonal variation), and whether the time trend is included in the model ($\gamma \neq 0$) or not. This is seen from table 2, where the bold zeros are not numerical values, but rather refer to no existing model parameters.

On the basis of the three explanations of fluctuations presented above, three different models can be developed to describe the dynamics that cause the observed fluctuations. The aim of this exercise is to isolate the one explanation that tends to be the most important in understanding the dynamics of the fluctuations.

Results

The results of maximizing the log-likelihood functions of the eight models, designated Model 1 – Model 8, are presented in table 2.

The estimated value of the effort-output elasticity, α, is just above 1.2 for all eight models shown in table 2. Variations in α are small, even though model specifications vary significantly. Thus, the estimation results for α are robust, and the greater than unity value signifies increasing returns to effort, hours of trawling. (This and other results are discussed in the next section). The estimated values of the stock-output elasticity, β, show considerable differences between the investigated models. Values vary between 0.255 and 0.778. In particular, the values seem to be related to the technological change parameter, γ, and the seasonality parameters k_i ($i = 2, \ldots, 5$). With γ fixed to zero, the β-value is between 0.255 and 0.365,

Table 2

Parameter Estimates and Test Statistics: Results of the Statistical Analysis, Parameter Estimates, and Test Statistics

	M1	M2	M3	M4	M5	M6	M7	M8
α	1.201	1.214	1.206	1.215	1.244	1.232	1.244	1.232
β	0.365	0.362	0.778	0.777	0.255	0.256	0.424	0.424
φ	**0**	0.374	**0**	0.364	**0**	0.293	**0**	0.291
γ	**0**	**0**	0.053	0.053	**0**	**0**	0.021	0.021
k_1	–6.90	–6.92	–16.92	–16.95	–7.996	–7.965	–12.04	–12.01
k_2	**0**	**0**	**0**	**0**	–39.40	–39.68	–39.06	–42.32
k_3	**0**	**0**	**0**	**0**	–0.129	–0.128	–0.130	–0.120
k_4	**0**	**0**	**0**	**0**	2.420	2.417	2.408	2.408
k_5	**0**	**0**	**0**	**0**	3.269	3.269	3.261	3.260
AIC*	43,425.3	34,848.4	39,850.7	34,479.9	35,856.3	32,446.6	35,726.5	32,395.5
DW*	1.252	2.215	1.272	2.206	1.415	2.142	1.419	2.141
R^{2*}	0.228	0.336	0.240	0.341	0.317	0.376	0.319	0.377
F*	1,504.43	496.76	1,659.92	545.23	1,817.43	60.58	3,513.70	2,532.5

Note: Bold zeros are not numerical values, but rather refer to no existing parameters of the models.

* AIC: Akaike's Information Criterion, DW: Durbin-Watson test statistic, R^2: Correlation coefficient, F: F-test, all F-values are significant $p < 0.001$.

which is at the lowest range of β in table 2. For each of the Models 5–8, which include the sine-function describing seasonal fluctuations, the β-value is lower than in its corresponding model, among M1-M4, without seasonal changes. Thus, by replacing the fixed catchability coefficient with the sine-function, the estimated stock-output elasticity decreases.

According to the test statistics AIC, DW, R^2, and F presented in table 2, Model 8 has the best performance. This is the most advanced model, including all three features that define the different models: the autoregressive error term, the technological change term, and the catchability seasonal sine-function. Model 8 has the lowest AIC value, it explains about 38% of the observed variation in the data (R^2), and the Durbin-Watson test statistics are close to 2. The latter confirms that the error terms, v_t, are almost serially uncorrelated. The F-value increases when γ is introduced in Model 8 compared to Model 6, which does not include the technological change term. Also the autoregressive error term ($\varphi \neq 0$) seems to be of significant importance (moving from M7 to M8) in improving the statistical performance of the model. In addition, parameters α and β are just weakly affected by the inclusion of $\varphi \neq 0$ in the model (see M2 compared with M1 and M8 compared with M7).

Table 2 shows that the introduction of seasonal change ($k \neq 0$) in the models has just a minor effect on the effort-output elasticity, α, but a stronger (negative) effect on the stock-output elasticity, β (compare models; *e.g.*, M8 to M4 and M7 to M3). Another effect of including seasonal change is a reduction in the time trend parameter, γ.

The time trend parameter, γ, estimated at 0.021 and 0.053, may be interpreted as the annual neutral technological change — 2.1 and 5.3%, respectively. Table 2 shows that the lowest value of this parameter is found for the best performing models, those that have seasonal variations included (compare *e.g.*, M2 to M1 and M8 to M7).

The importance of including seasonal changes in the models is demonstrated in figure 4, where the catchability factor of the low season is less than 30% of the catchability maximum the same year. This phenomenon is also reflected in the box plot of the raw data in figure 2.

Discussion

This discussion focuses on Model 8, which is the best performing model according to all four test-statistics shown in table 2. However, this model explains less than 40% of the total variation in the data set, mirroring the inherent uncertainty found in fish harvesting activities. This may be considered a low explanation rate, especially with nine parameters and a large database of close to 38,000 observations. Perhaps other models could have explained a larger fraction of the variation in this specific data set. However, the statistical performance is only one dimension of a production model. Another dimension is how the model fits the theoretical basis of catch production. The Cobb-Douglas production function is a formal representation of what we *a priori* would expect production of catch to look like, satisfying basic constraints of no effort giving no catch, for example. Obviously there are functional forms other than C-D that would satisfy this particular constraint; *i.e.*, quadratic equations.

The harvest and effort data used in this study are, in principle, exact figures, but they may include errors due to measurement, reporting, and registration mistakes, *etc.* Nevertheless, with respect to sureness, they differ from the biomass data that are based on once-a-year stock assessments of ICES and on our own daily biomass

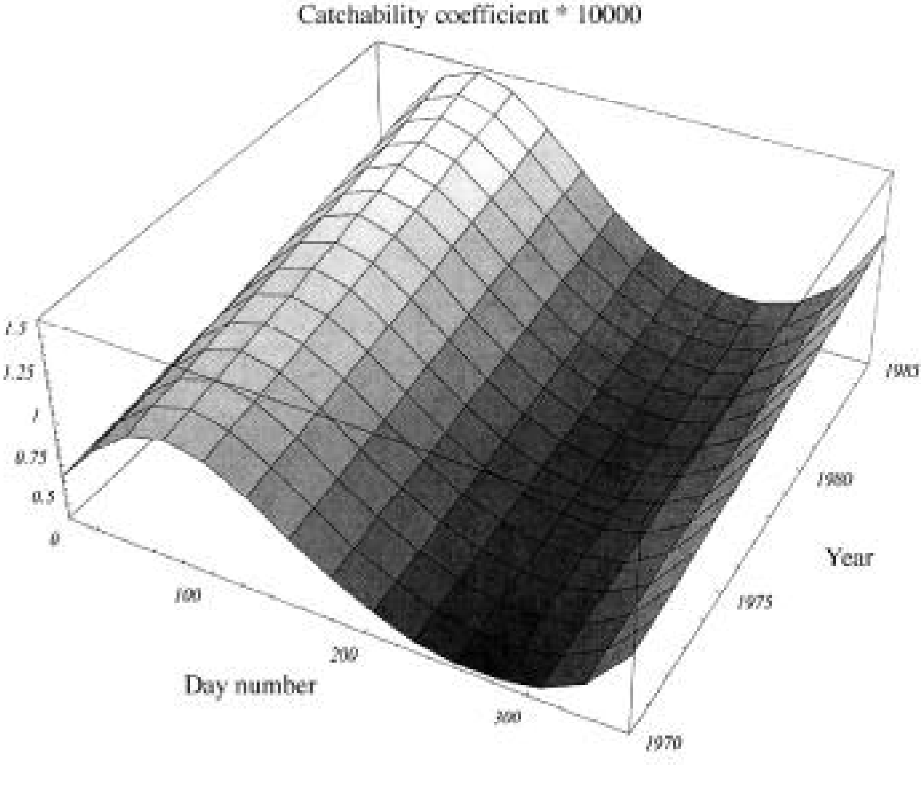

Figure 4. Seasonal Catchability Coefficients

The graph shows the values of the catchability coefficient times 10,000 [equation (7)], multiplied by the technology term $e^{\gamma t}$, as a function of day number within a year, in the period 1971–85. The sample of all q-values of every day in the period is presented as a surface.

estimates calculated by polynomial interpolation, as noted above. Thus, biomass data are estimates with uncertainty, even though the exact nature of this uncertainty is not known (for a review of uncertainty issues in fisheries biology see Myers and Mertz 1998). The regression estimates shown in table 2 would have had a larger standard deviation if uncertainty of biomass estimates had been included. However, the estimates presented are unbiased and can be used for the purpose of this study.

According to the α estimate (table 2 shows that this is greater than 1%), the percentage increase in the short-term, per-hour catches is greater than the percentage increase in total number of trawl hours, *ceteris paribus*. This may seem somewhat strange and counterintuitive. However, this could be due to better information on the fish availability, either by observations of the positions of other vessels or by direct sharing of information between vessels. There may also be other explanations. First, there may be a systematic trend in the data material towards increased activity as the fish abundance increases beyond what is modelled. Actually, fishers fish to make money, implying that more effort is attracted to the fishing grounds when harvest rates are high. Second, the trawler licensing system in use in this particular fishery may effectively have hindered the entry of more effort, measured in trawl hours, that could have increased the scale of fish harvest and reduced the effort-output elasticity. Third, it could be that other specifications of the model shed light on these issues. Production and stock data used in this study, combined with economic data at the vessel level, would allow for modelling of economic behaviour. As with all production processes summarized in a production function, the underlying causality of fish harvesting is nevertheless economic in nature. Thus, directly modelling economic behaviour may give other results for α, or an equivalent parameter, than presented in table 2.

The β estimate predicts a harvest increase of 0.424% when the stock biomass increases 1%. One interpretation of this is that the density of cod at the trawling grounds is less than proportionally affected by changes in the total stock biomass. Another interpretation is that trawlers adjust towing hours per haul, speed, or other control variables to the availability of fish. There are probably several factors behind this result.

If catch data had allowed separating cohorts in the statistical analyses, the β-values might be age dependent as well as stock and gear dependent. Schooling habits of younger year classes are a well-known biological phenomenon, and this would probably result in lower β-values than shown in table 2. However, at this stage, this is simply a hypothesis, and it still remains to be seen if an analysis based on cohorts could increase the explained percentage of the observed variation in day catches.

Functional forms of harvest in relation to fishing mortality, F, and fishing effort, E, were discussed above. The estimation results for α and β presented in table 2 show that functions (1) and (2) are most likely not valid for this fishery. This implies that use of such functions for cod assessment and management purposes; *e.g.*, VPA tuning for Northeast Arctic cod, may lead to skewed results.

The existence of 1.order-autocorrelation, as demonstrated with φ in table 2, indicates that the unexplained catch today mainly depends on yesterday's fishing conditions. A reason for autocorrelation in the error term is factors not included in the model, such as fish migration or weather conditions. Autoregressive processes of higher order have been tested, without giving the model a higher explanatory rate.

As noted above, the time trend parameter, γ, may be interpreted as the annual percentage technological change. Table 2 shows that for Model 8 technological change increases the efficiency of the trawl fishery about 2% on an annual basis, which is consistent with the findings of Hannesson (1983) and Flaaten (1987). Hannesson (1983) found a technological progress of 2–7% per year, while Flaaten (1987) found it to be 1–4% per year.

As it is treated in this paper, technological progress is of the "neutral" type, shifting the harvest function upward over time. It is possible, however, that technological progress affects the parameters of the harvest function; in particular, the stock-output and the effort-output elasticity. The changes in R^2, although weak as a result of including the term for technological progress, indicate that such an effect on parameters could be the case. *A priori* there is reason to expect that technological progress may affect α. This would happen if it takes the form of better fish finding equipment, for example, enabling fishermen to locate concentrations of fish more effectively. However, data on investment in new technology was not available for this study.

The k estimators of equation (7) reflect the expected larger catchability of cod in the first part of each year. Table 2 shows that including the seasonal change term significantly improves the reliability of the estimation results. The maximum catchability corresponds to the spawning season and the capelin-feeding season, with an increased cod density along the coast related to its spawning and feeding migration.

The results show that an assumption of linearity between fishing mortality and fishing effort has to be modified, at least regarding the bottom trawl fisheries for cod. The analyses of the impact this will have on long-term fisheries management was not a part of this study, but it certainly has to be part of a long-term strategy of how to exploit the fish resources. Differences in stock output elasticities between gears could have important economic consequences, as the relative profitability of gear types changes when the stock biomass rises or falls. This certainly complicates the question of what gear and vessel are the most efficient, but increased information in this area will hopefully give more adequate and useful input to fisheries management.

Conclusion

The aim of this project has been to study to what extent catch of a demersal fish species varies with fishing effort, stock size, and other factors. A detailed and comprehensive set of daily catch and effort data for the cod fisheries of 18 Norwegian bottom trawlers was obtained for the period 1971–85. Daily biomass estimates were calculated by polynomial interpolation of the annual 1 January estimates of ICES. By maximizing the log-likelihood function by numerical methods, parameter estimates and performance indicators of the different models were obtained. Several models were tested, and this paper presents those that are most robust from a statistical point of view. The best result was obtained for a model allowing for seasonal changes of harvest efficiency and with an autocorrelated error term. For this model, the stock-output elasticity is estimated at around 0.4, which implies that a 10% increase in stock level increases catch with around 4% for a given effort level. However, the seasonal changes in catchability are significant, with the lowest intra-annual catchability being less than 30% of the annual maximum. Thus, stock levels have a significant impact on CPUE for this trawl fishery, and seasonal output fluctuations are great. The average neutral technological progress has been estimated at 2.1% on an annual basis for this group of vessels.

Even if the statistical methods used are robust and have given significant results, there are still unanswered questions needing further research. First, could other statistical methods; *e.g.*, panel data approaches, improve the reliability of the results? Would such methods significantly change the results for the models used in this paper or only in the case of other model specifications? Second, would a more thorough analysis of technological change yield different results, both for the annual technological progress parameter and for other model parameters? In this paper, technological progress is of the "neutral" type, shifting the harvest function upward over time. Third, would it be possible to obtain age/cohort distributed catch data, and would age/cohort specific effort-output and stock-output elasticities vary much compared to the estimates presented in this paper? Such data were not available for this study, and it still remains to be seen if analysis based on cohorts could increase the explained percentage of the observed variation in daily catches.

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