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Catch, Stock Elasticity and an Implicit Index of Fishing Effort

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by

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Catch, Stock Elasticity and an Implicit Index of Fishing Effort

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Abstract: Economists are interested in the relationship between fishing effort and stock size, and how these impacts catch levels. The interest lies in the stock elasticity where it is thought that for pelagic fish species it is close to zero and for demersal fish stocks closer to one. We statistically model and estimate the relationship between stock size and catch for two species, Northeast Arctic cod and saithe. In doing so we are able to recover estimates of stock elasticity but also estimates of catchability coefficients for different age classes and importantly an implicit index of fishing effort. Data on observed catch and a measure of biomass-at-age are available from the International Council for the Exploration of the Sea. The generated stock data are problematic and instrumental variables and bootstrapping are used in estimation. Time-series techniques applied to panel data are used to statistically motivate the estimation, which is carried out within a two-way panel framework.

JEL: C72, Q22
Keywords: Stock elasticity, Fishing Effort, Age Class, Catchability Coefficients

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1. Introduction

Economists have long been interested in the relationship between fishing effort and stock size, and the impact on catch[i] levels (Hannesson, 1993). The primary interest lies in the stock elasticity with respect to catch. Where, on one hand, it is thought that for pelagic fish species the stock elasticity is close to zero (Ulltang, 1980; Butterworth 1981; Bjørndal, 1987). The idea here is that pelagic species form schools and have a lumpy distribution in the sea. In such cases, once a school of fish has been targeted, the actual stock of the species is moot to the harvest/profit process and thus the stock elasticity should be close to zero (Hannesson, 1983; Flaaten, 1987). On the other hand, for demersal fish stocks the stock elasticity is thought to be closer to one (Schaefer, 1957). The idea here is that demersal species in the fishing area are thought to be roughly evenly dispersed over the sea floor and well modeled using a uniform spatial distribution. In this case, an increase in stock size will proportionately increase the density of the stock and catch per unit of effort (Sandberg, 2006). In application, the actual size of the stock elasticity for either pelagic or demersal species is an empirical question.

The purpose of this paper is to statistically model and estimate the relationship between stock size and catch for two species, Northeast Arctic saithe (*Pollachius virens*) and Northeast Arctic cod (*Gadus morhus*). Both species are demersal but saithe, a member of the cod family, can occasionally behave like pelagic species in that it congregates in schools. We speculate that cod should show a stock elasticity close to one and saithe less than one. In doing so we are able to recover estimates of stock elasticity but also estimates of catchability coefficients for different age classes and importantly an implicit index of fishing effort.[ii] Fishing effort is difficult to model directly because it is a combination of different vessel types, different gear types, different vintage of capital equipment and so on.[iii] In practice economists use some proxy for fishing effort typically vessel numbers as a ratio of days at sea, which introduces serious econometric problems of endogeneity and inconsistent coefficients (Gordon, 2013). Our empirical research implicitly recovers an index of fishing effort based on actual catch data and estimates of stock size.

Biologists are interested in measures of fishing effort that would be directly proportional to the mortality it generates in the stock (Jennings *et al*., 2001). If fishing effort is directly proportional to mortality, catch per unit effort could be used as an index to the size of the stock. But this depends on an assumption of uniform spatial distribution of the stock of fish within the fishing area. Under this assumption a unit of fishing effort would always remove a given fraction of fish in the stock.[iv] However, if the distribution were lumpy a unit of fishing effort would always remove a given quantity of fish and thus an increasing fraction of fish in the stock.[v]

Catchability coefficients by year class are of interest because they are a measure of gear efficiency and related to gear selectivity (May, 1984). The probability of a fish being caught at different age levels depends on both biological factors (availability, behaviour, the size and shape of the fish, season, environment, other fish species, etc.) and technological factors (gear type, gear position, management skill, etc.) (Jul-Larsen *et al*., 2003). Catchability coefficients are really a composite factor where 'fish catchability' implies primarily changes in fish behaviour (May, 1984), whereas 'fishing efficiency' indicates changes in fishing practices or in relative fishing power (Neis *et al*., 1999). We recover estimates of catchability coefficients by age class that are informative of gear selectivity.

In application we use an interesting data set made available from the International Council for the Exploration of the Sea (ICES).[vi] The data generated using Virtual Population Analysis

(VPA) is interesting in that it is rich in its coverage of catch, mortality and stock size information but mortality and stock size are *generated* variables based on biological assumptions, actual catch levels and assumed decay functions. Generated regressors cause some econometric problems in estimation in achieving consistent and efficient recovery of parameters (Pagan, 1984; Zhang and Smith, 2011). In application an instrumental variable technique is used to address this issue. For the problem at hand we collect data for two species cod and saithe. For these species the data are organized in a panel setting; for cod we have age classes 3–13 for a 35 year period (1977-2011) giving a total cross-section time-series data set of 385 observations, for saithe we have age classes 3-15 for a 35 year period (1977-2011) giving a total cross-section time-series data set of 455 observations. Each data set is balanced in a panel setting. Time-series techniques applied to panel data are used to statistically motivate the estimation, which is carried out within a two-way panel framework. We are careful to account for clustered residuals allowing for both heteroskedasticity and autocorrelation within the panels. The estimated equations are validated based on residual analysis and robustness checks. It is important to emphasize that our estimated results for stock elasticity, catchability coefficients and fishing effort are a function of the data generating process and environmental design of VPA procedures.

The paper is organized as follows. Given the ICES data and the econometric issues that arise, we start in Section 2 by providing a detailed description of the data generating process and our methodology for dealing with the empirical problems. In Section 3, based on early work by Hannesson (1993) a simple model is presented of catch rates and stock size. The model, although straightforward captures the bioeconomic relationship between catch and stock size and allows direct specification of the econometric panel equation. Section 4 provides a brief summary description of the data used in empirical work and details the econometric equation estimated. Section 5 describes the empirical research strategy and presents results. Section 6 concludes.

2. Data Issues and Empirical Methodology

The VPA method for generating stock data is somewhat involved and worth outlining in detail with particular emphasizes for econometric modelling. In general the procedure for predicting stock in the previous period relies on biological assumptions and back forecasting based on current and previous period actual catch levels.[vii] To make this clear, define catch in each period according to time period t, $(t = 1, 2, \cdots 35)$, age class a, (for cod $a = 3, 4, \cdots, 11$ and for saithe $a = 3, 4, \cdots, 15$) and cohort c, $(c = -9, -8, \cdots 35)$. (We define cohort 1 as age class three in time period 1.) So, catch in period t, age class a and cohort c is written, $C^t_{a,c}$. Of particular importance in VPA methods is the cohort. Using cod as the example, Table 1 sets up the panel framework for catch levels by age class and time. (Notice age class 13 in time period 1 is cohort -9.)

The columns define the catch distribution by age class for a given year. The rows define the catch levels at age for different cohorts over the time period studied. The diagonal elements define catch level of cohorts over time. VPA analysis uses the diagonal elements, cohorts, in order to back forecast stock level. For example to define stock levels in period 1, age class 3 cohort 1, we need catch levels in period 1 and 2 for cohort 1 or; $\hat{S}^1_{3,1} = S^1_{3,1}(C^1_{3,1}, C^2_{4,1})$ or in general $\hat{S}^t_{a,c} = S^t_{a,c}(C^t_{a,c}, C^{t+1}_{a+1,c})$.

The generated stock data is arranged as in Table 2. The important point to emphasize in Table 2 is that the diagonal elements i.e., generated stock values following a cohort are biologically and mathematically linked by VPA procedures and of course an econometric equation following the cohort would merely approximate the deterministic VPA decay equations. To be clear for cohorts pairwise stock estimates are linked by common catch variables in different periods. But notice that for any given age class (i.e. a row) stock values are not linked by common catch variables. So, for each element in a row the stock estimate represents an independent (i.e., based on different catch values) draw from the data generating process. Of course, all stock estimates are subject to the VPA framework of analysis as are all econometric parameters recovered in estimation. Subject to this caveat, our empirical approach is to use the generated stock data based on known catch levels to recover the parameters of interest in our study. To be clear the data will be organized by age-class panels. For example, panel one defines the data for age class three as reported in Table 3.

By writing the data as in Table 3 it is clear that generated VPA stock estimates must be correlated with the error term in a regression equation of catch on stock because current stock is a function of current catch. To achieve consistent estimates of the econometric equation we need to instrument out current catch in the VPA stock estimate. Table 2 provides us with some insight into a possible instrument. For instance in period 2 age class 4 of Table 2 predicted stock is written $S^2_{4,1}(C^2_{4,1}, C^3_{5,1})$ but notice that the argument $C^2_{4,1}$ appears also as an argument in predicting stock in period 1 age class 3; $S^1_{3,1}(C^1_{3,1}, C^2_{4,1})$. Implicitly solving we observe that $C^2_{4,1} = {S^{-1}}^1_{3,1}(C^1_{3,1})$, which implies correlation between the cohort lagged catch variable and current catch and provides an instrument to address the correlation problem identified in Table 3. It might be argued that the cohort lagged catch variable merely reflects common shocks in the VPA stock generating process but this ignores the importance of exogenous and independent current shocks to catch levels based on say, current surface weather conditions impacting current fishing effort and independent of VPA stock estimates. Consequently, for each stock estimate we instrument out $C_{a,c}^{t}$ using $C_{a-1,c}^{t-1}$. To be clear the instrument is the predicted values from the first stage regression of $\hat{S}_{a,c}^{t} = \beta C_{a-1,c}^{t-1} + \gamma C_{a+1,c}^{t+1} + \alpha_a + \delta t + \vartheta_{it}$, where α_a is the age-class fixed effect, t dummy outs time shocks and ϑ_{it} is a random error term. The second stage estimation uses the predicted values in place of VPA stock estimates and bootstrapping techniques are used to approximate efficient standard errors.

3. The Model

We follow Hannesson (1993) in setting up a simple and direct relationship amongst catch, fishing effort and stock size. To do this we simply write catch (C) per unit effort (E) proportional to stock size or

$$\frac{C}{E} = qS \tag{1}$$

where q is a catchability coefficient, a parameter expressing the vulnerability of the fish to gear selectivity. If the catch per unit effort is less than proportional to S, we need to modify equation (1) as

$$\frac{C}{E} = qS^{b} \tag{2}$$

where the parameter b is the stock elasticity with respect to catch per unit effort.[viii] Rewriting equation (2) we are able to write catch as a function of fishing effort and stock size or

$$C = qES^{b} \tag{3}$$

Although simple and straightforward equation (3) allows for a clear and direct test of the stock elasticity were the null of $H_o\colon b = 0$ defines a pelagic stock and an indirect test of a lumpy distribution of fish density, and the null of $H_o\colon b = 1$ defines a demersal stock and an indirect test of a uniform spatial distribution of fish density. In anticipation of the empirical results, we do expect saithe to have a measured stock elasticity between zero and one indicating some schooling behaviour patterns for the species whereas cod is expected to have a measured stock elasticity statistically near one.

In anticipation of the age structured time-series data available for estimation we rewrite equation (3) by age structure and time period, and introduce a random error term identified for each panel and time period as

$$C_{a,i}^{t} = q_{a,i} E_{a,i}^{t} {S_{a,i}^{t}}^{b} e^{\varepsilon_{a,i}^{t}} \tag{4}$$

where $q_{a,i}$ is the catchability coefficient for age class a, species i, $E_{a,i}^{t}$ is an index of fishing effort for age class a, species i in year t, ${S_{a,i}^{t}}^{b}$ is the age specific biomass for species i, age class a, in year t. Biologically the parameter b is restricted between zero and one but we maintain this as a testable parameter in estimation. Finally, $\varepsilon_{a,i}^{t}$ is the idiosyncratic error term for species i, age class a, in year t. The error term captures all additional factors impacting catch levels.

Note that in equation (4) we assume an elasticity of effort equal to one. Although this is a common assumption in biological work (see, Schaefer, (1954), in application this may not be true, in which case our measure of the implicit index of effort will also include a measure of the elasticity. Given the identification demands for sorting out catchability and effort variables in equation (4) we are not able to identify a specific measure for the elasticity of effort.

4. Data and Empirical Equation

The ICES (2012) publish catch and biomass-at-age for a number of fish stocks in the North Atlantic. Biomass-at-age estimates are based on virtual population analysis. In this paper we are interested in the Northeast Arctic cod and saithe stocks. There is some question as to the accuracy of the estimates of the ICES data[ix] prior to the 1970's and this combined with the establishment of the exclusive economic zones for both Norway and the Soviet Union in 1976, set our decision to start the data selection in 1977. For Northeast Arctic cod we have 3-13 age classes over a 35-year period (1977-2011) and for saithe we have 3-15 age classes over the same time period.

To provide a flavour for the variation in the data we graph out in Figures 1a and 1b landings and total biomass for the period 1977-2011 for cod and saithe, respectively. For cod and saithe landings are the total landings for all age classes. For cod, Figure 1a, prior to 1990 although a total quota was agreed on between Norway and Soviet Union exceptions were allowed and enforcement inconsistent, resulting in a high level of landings and reduced biomass (Bergland and Pedersen, 2000). After 1990 TAC levels were enforced and Norway imposed vessel quotas. Figure 1b for saithe shows a somewhat different evolution of catch and biomass over the period. Saithe does not have the high-value status of cod but the fishery was regulated in a similar manner. From time to time we observe peaks of increased catch level while the stock size declines. This is obvious around 1990 when catches for a time increased while the stock size declined. The 1990 incident is probably a result of compensating for the poor cod fishery at that time.

Figure 2 offers a different perspective and shows catch at age for both cod and saithe. Here we observe that for cod the age groups 5-7 dominate the catches in terms of biomass but for saithe we see that age group 4 is by far the most dominant one. Finally, to emphasize the richness of the data, Figure 3a and 3b show catches for cod and saithe, respectively, plotted against biomass for four age groups. For cod age group three we see low levels of catch at all biomass levels, whereas, for age group five and six we observe high variation in catch levels at different biomass levels. For age group twelve notice the very low stock values and again high correlation between landings and stock levels. For saithe we observe high variation in catch at all age groups and all stock levels except age group 12.

The panel data structure of the data set is crucial to the econometric identification of Equation (4). To address the identification issue write equation (4) taking logs of both sides or

$$\ln(C_{a,i}^{t}) = \ln(q_{a,i}) + \ln(E_{a,i}^{t}) + b\ln(S_{a,i}^{t}) + \varepsilon_{a,i}^{t} \tag{5}$$

With cross-section data only we would not be able to identify fishing effort whereas, time-series data alone would not allow identification of the catchability coefficient by age group. However, the panel structure will allow identification and estimation of both catchability coefficients for each species and an implicit index of fishing effort over time. In estimation we use both a within estimator and for a robustness check a two-way fixed-effect estimator, allowing binary variables on age to recover catchability coefficients and binary variables on year to recover an implicit index of fishing effort. The base period is age group three in 1977.

As a practical matter good estimates of equation (5) require good variation in the data. With panel data, variation can occur within the panel and between the panels. Table 4 reports this variation for catch and stock size for each species, cod and saithe. For both species with the exception of the within variation in catch for saithe, we measure more variation both within and between for stock size compared to catch. And, between variation dominates within variation for both species.

5. Econometric Results

For both the cod and saithe, our empirical strategy is first to test in a panel setting the statistical validity (i.e., stationarity of the variables) of the empirical specification of equation (5). Second, we generate and validate instrumental variables for stock for both cod and saithe as defined in

Section 2. Third, we apply a within estimator to equation (5) that is specified as a two-way fixed-effect model correcting for clustered residuals and accounting for both heteroskedasticity and autocorrelation within the panels. Finally, we validate the estimated equations by evaluation of the predicted residuals and then report results.

Testing for stationarity in a panel setting uses both the variation over time, which is standard in time-series econometrics and also variation across panels. We evaluate the stationary prospects of our model using two statistics for testing unit-root hypotheses in panels. Levin *et al.* (2002) (hereafter the LLC test) developed procedures that test the null hypothesis that for each age group the variables catch and stock have unit root versus the alternative hypothesis of stationary. The pooling approach across age groups yields greater power in testing than performing a separate unit-root test for each age group.[x] The second test is a Fisher-type test where individual Dickey-Fuller statistics for each variable separately are combined using meta-analysis to generate a test for stationarity in the panels. The null and alternative hypotheses are as defined for the LLC test. Choi (2001) showed that if the time dimension is large and the number of cross-sectional units is finite the test statistic follows the inverse normal.

The LLC and Fisher-type test statistics for fishing mortality and biomass for both species cod and saithe are reported in Table 5. We observe for each variable and for each statistical test that the null hypothesis of unit root can be rejected. This provides statistical evidence that within the panel data framework all variables have stochastic properties amenable to equilibrium evaluation and provides statistical support for the model as specified in equation (5).

Our instrumental[xi] variable for stock was defined generally in Section 2. Our strategy is to rely on properties of VPA analysis to support the use of lagged cohort catch as an appropriate variable to build the IV. Of course, with both past and forward lag in the IV equation we lose degrees of freedom and age group three. However, ICES provides additional catch information outside of our period of analysis that allows us to recover all but 45 observations for cod and 47 observations for saithe. The IV equation is written as:

$$\ln\left(S_{a,c}^{t}\right) = \ln\left(q_{i,a}\right) + \ln\left(E_{i,t}\right) + \delta_1^{IV} \ln C_{a-1,c}^{t-1} + \delta_2^{IV} lnC_{a+1,c}^{t+1} + \vartheta_{a,c}^{t} \quad (6)$$

The statistical strength of the lagged catch variable in equation (6) is important in generating good estimates based on the IV in catch equation (5). We test the null that $H_0: \delta_1^{IV} = 0$, with generated F-statistics of 11.36 (0.00) and 7.94 (0.00) for cod and saithe, respectively (p-values in parentheses). These tests provide some validation for using lagged catch as an instrument. Consequently, based on both the stationariy and endogeneity tests we are statistically confident in the empirical specification of equation (5) and we move on to an IV estimation procedure to recover parameters.

We apply a within estimator with fixed time effects corrected for heteroskedasticity and autocorrelation within the panels and report the full econometric results in the Appendix. As robustness check we re-estimate the models using a generalized linear estimator with binary variables defining both age and year effects. The results obtained were very similar to the within panel estimator. For the equations presented in the Appendix the residuals are stationary and show no systematic behaviour. We will present the econometric results in three parts; catchability coefficients, implicit index of fishing effort and finally stock elasticities.

Figure 4 graphs out catchability coefficients by age group for both cod and saithe. The coefficients are averaged over the full period of study. For both cod and saithe we observe a clear negative trend over age class. This would imply weak age selectivity over all age groups, except age class four. For saithe this seems reasonable given the many gear types used in the fishery including the purse seine that targets all year classes. For cod these results are somewhat at odds with Figure 2 that shows age class six presenting the largest catch in tonnage. Moreover, for a trawler fishery we would have expected well-designed gear selectivity in targeting the older age codfish. Notwithstanding, the profiles can be taken as evidence of growth overfishing where fishing pressure is as heavy on the young fish as the old. These results are consistent with recent work by Diekert (2012) and Diekert *et al*. (2010).

Figure 5 reports the implicit index of fishing effort over the period 1977-2011 for age group 9 for both cod and saithe. This is an interesting result because it represents the actual index of fishing effort required to reflect actual catch. Of course, again this is subject to the VPA environment for data generation. Over time and for both species we see a declining trend in effort reflecting both improved fisheries management and improved efficiency in harvesting techniques. For cod notice the large drop in fishing effort in 1990 reflecting a strong effort on part of regulators to enforce the TAC and serious decline in stock levels. Fishing effort on saithe seems to be more variable and erratic compared to cod and likely reflects the low value status of saithe relative to cod.

Finally, the estimates of the stock elasticities are reported in Table 6. We report estimates of the stock elasticity and tests of the null hypothesis that $b = 0 \; and \; b = 1.$ The first row headed 'Overall' uses the entire period and recovers the stock elasticity. For both cod and saithe it is easy to reject a stock elasticity of zero but we cannot reject a stock elasticity equal to one. Because saithe does have the possibility of schooling behaviour we had expected to observe elasticity between zero and one. We decide to subdivide the data by year based on Figure 1a and 1b. We define four year groups 1977-86, 1987-1996, 1997-2005 and 2006-2011. We re-estimate the model and introduce specific stock variables for the groups defined and report the results in the bottom half of Table 6. For cod the results are robust over all year groups and we cannot reject that the stock elasticity is equal to one. It is interesting that other cod studies found a stock elasticity different from zero but less than one (Sandberg, 2006; Eide *et al*., 2003; Hannesson, 1983). But our evidence shows that an elasticity of one is robust over the data period. On the other hand for saithe only in the first period do we observe a stock elasticity statistically between zero and one. This period (Figure 1b) represents a period of high catch levels (although catch levels fall drastically in 1986) and relatively low stock levels. This is consistent with an argument that the stock elasticity for saithe is not constant but may be a function of the level of the stock.

6. Conclusion

This paper provided a simple but useful statistical evaluation of the relationship between stock size and catch levels. In estimation we recover not only the stock elasticity but also catchability coefficients by age group and an implicit index of fishing effort. Data for observed catch levels and biomass-at-age are collected from the ICES for both the Northeast Artic cod and saithe. The results are interesting on four fronts: First, ICES stock data are generated based on current and future catch levels, biological assumptions and a deterministic decay function. This forces an instrumental variable to allow consistent estimation. We show how the matrix configuration of stock and catch allows us to define the lagged cohort catch level as an instrument to correct correlation of stock with the error term in the catch equation. Second, the stock elasticity estimates provide some support for the general notion that for demersal species like cod the stock elasticity is statistically close to one but on the other hand, for a species like saithe that although demersal exhibits behaviour somewhat similar to pelagic species, we found some statistical evidence that the elasticity may be a factor of the actual level of the stock of fish. During the period 1977-1987, a period of low stock levels we did measure a stock elasticity statistically between zero and one. Third, the catchability coefficients show that for both cod and saithe we see almost no selectivity across age groups. Finally, our index of fishing effort for both species shows a general downward trend over time, which is likely a function of improved fisheries management and fishing efficiency.

The benefit of the statistical approach used in this study is that it does not require detailed vessel level data but relies only on aggregate age related information on catch levels and biomass-at-age from which an implicit index of fishing effort is recovered in estimation, in addition to stock elasticities and catchability coefficients. A natural next step in research is to link the fishing effort index to data on the costs of fishing.[xii]

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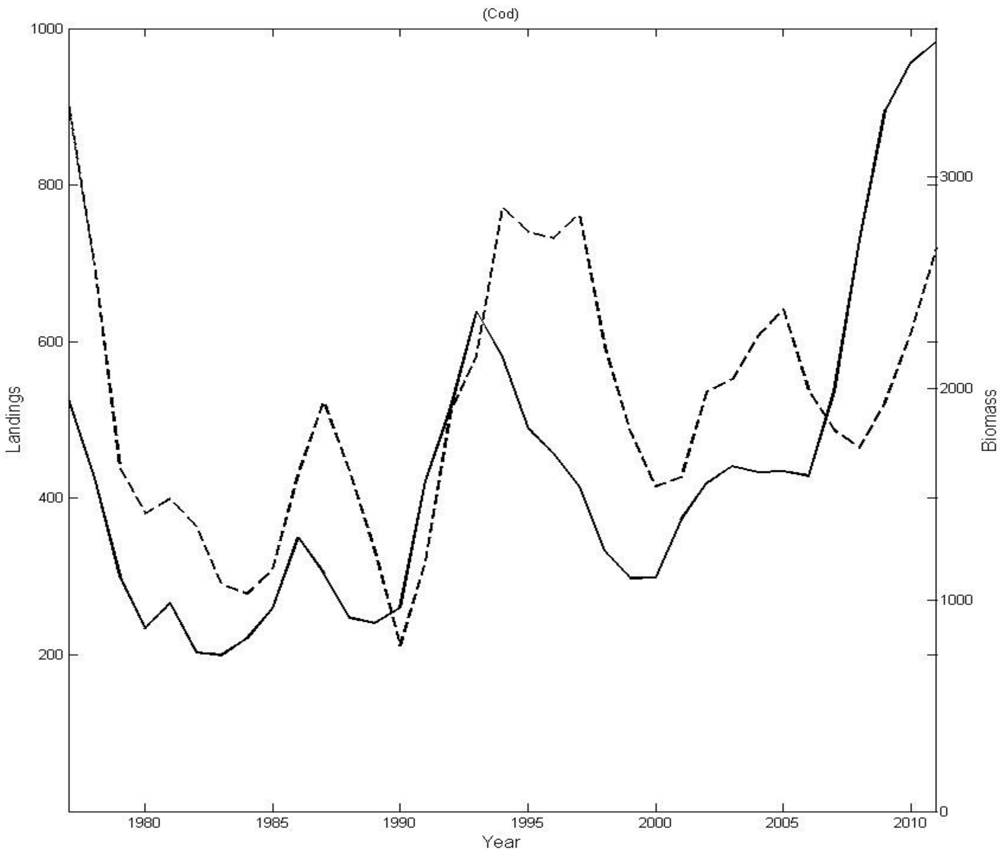

Figure 1a: Cod landings and total biomass, 1977-2011. The mean (age class 5-10) landings (dashed line) and the total biomass (solid line). Biomass in thousand tonnes.

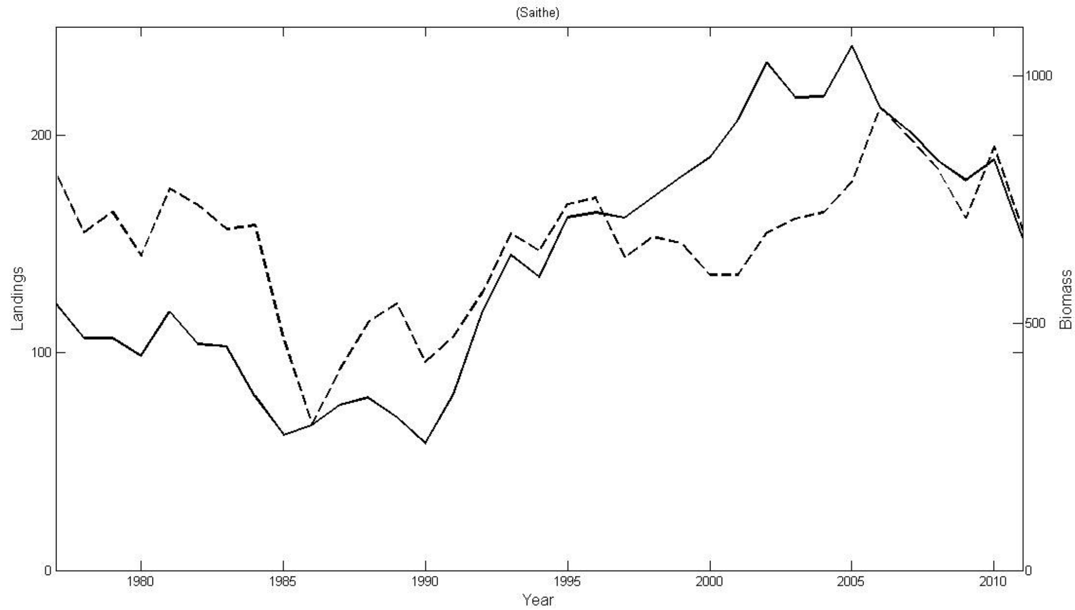

Figure 1b: Saithe landings and total biomass, 1977-2011. The mean (age class 4-13) landings (dashed line) and the total biomass (solid line). Biomass in thousand tonnes.

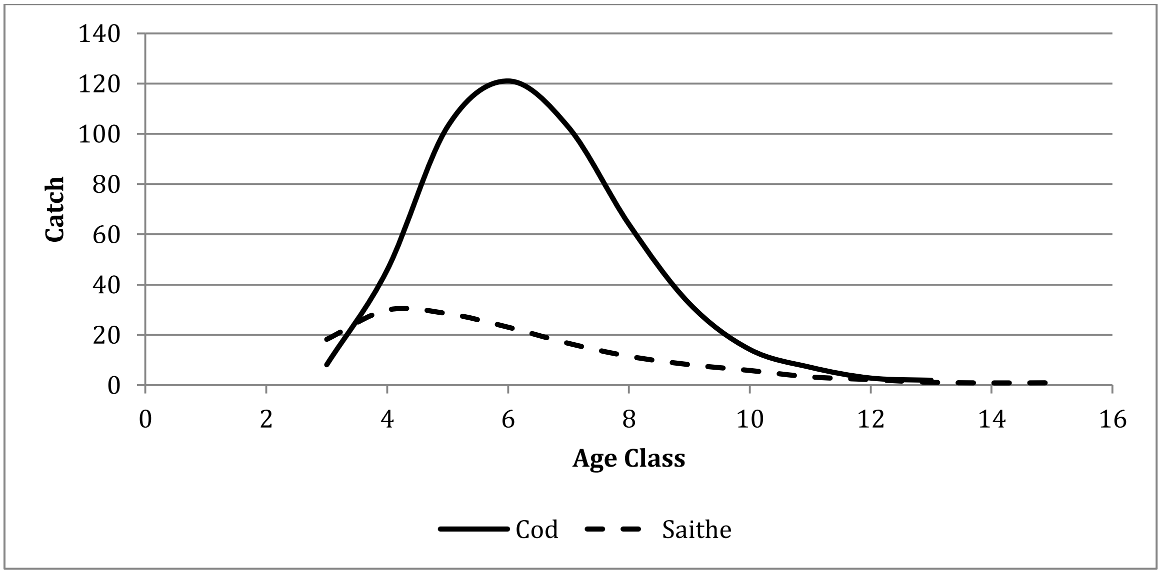

Figure 2: Catch by age class; Northeast Artic cod and saithe

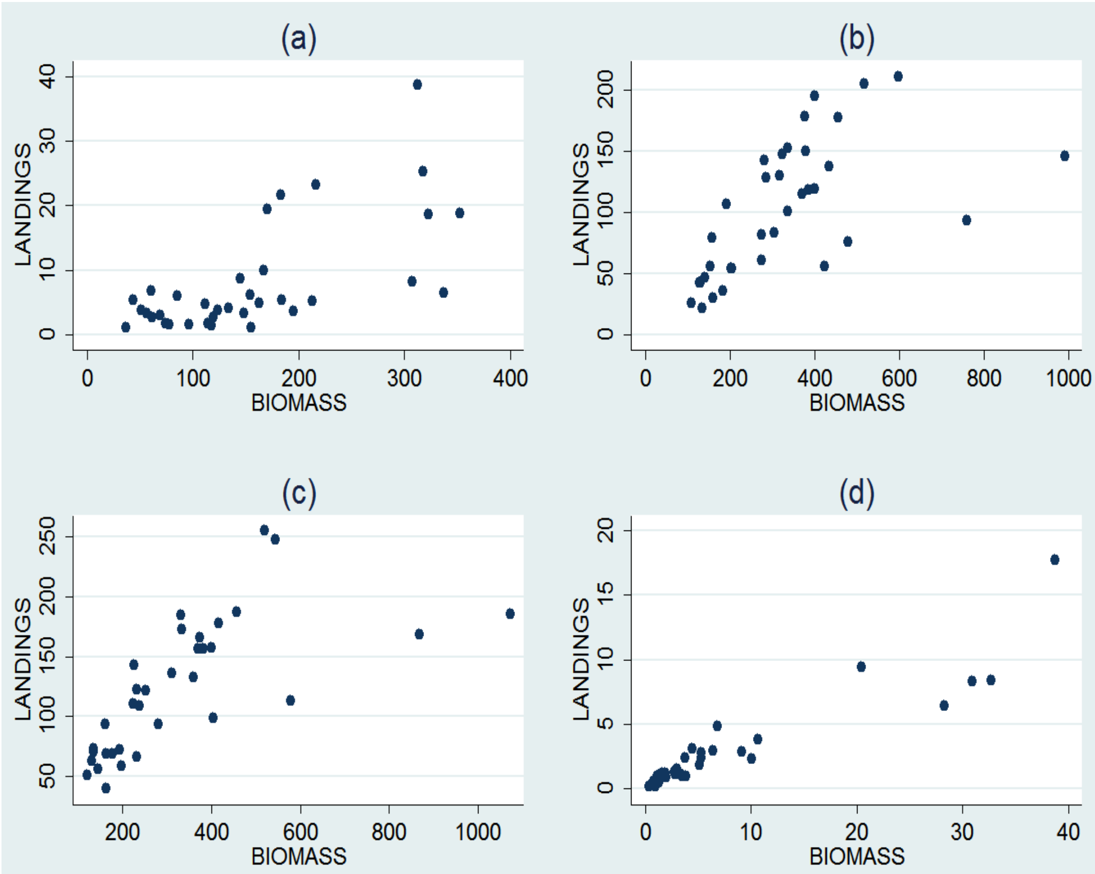

Figure 3a: Cod landings plotted against biomass (thousand tonnes). (a)- age group three, (b)- age group five, (c)- age group six, and (d)- age group 12.

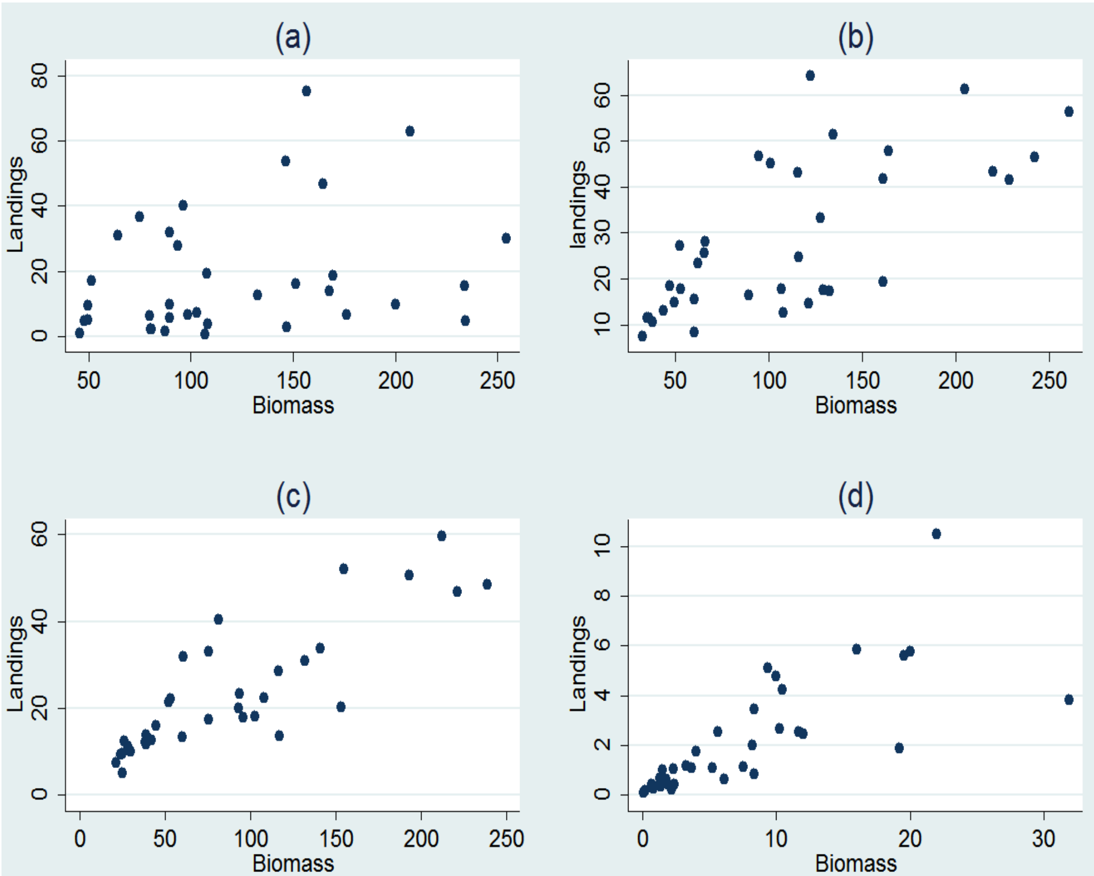

Figure 3b: Saithe landings plotted against biomass (thousand tonnes). (a)- age group three, (b)- age group five, (c)- age group six, and (d)- age group 12.

Figure 4: Catchability Coefficients for Cod and Saithe, Average values

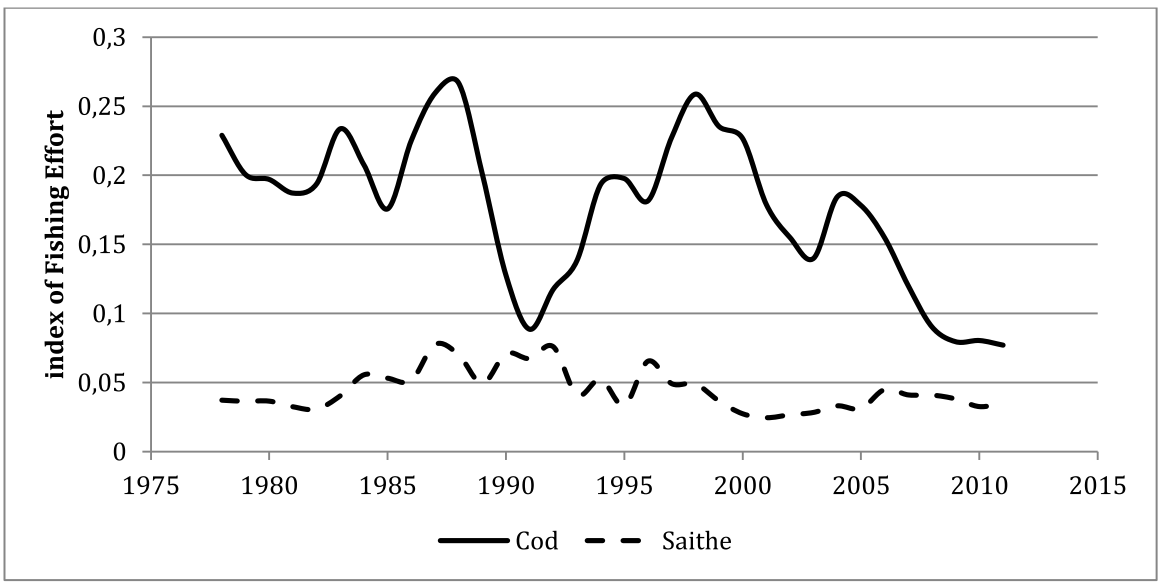

Figure 5: Implicit Index of Fishing Effort for Cod and Saithe, Age Group Nine

Table 1: Catch Levels					
	Time Period				
Age	1	2	3	⋯	35
3	$\boldsymbol{C^{1}_{3,1}}$	$C^{2}_{3,2}$	$C^{3}_{3,3}$	⋯	$C^{35}_{3,35}$
4	$C^{1}_{4,0}$	$\boldsymbol{C^{2}_{4,1}}$	$C^{3}_{4,2}$		
5	$C^{1}_{5,-1}$		$\boldsymbol{C^{3}_{5,1}}$		
⋮	⋮			⋱	
13	$C^{1}_{13,-9}$	⋯			$C^{35}_{13,25}$

Table 2: Stock Estimates				
	Time Period			
Age	1	2	3	⋯
3	$\boldsymbol{S^{1}_{3,1}(C^{1}_{3,1}, C^{2}_{4,1})}$	$S^{2}_{3,2}(C^{2}_{3,2}, C^{3}_{4,2})$	$S^{3}_{3,3}(C^{3}_{3,3}, C^{4}_{4,3})$	
4	$S^{1}_{4,0}(C^{1}_{4,0}, C^{2}_{4,0})$	$\boldsymbol{S^{2}_{4,1}(C^{2}_{4,1}, C^{3}_{5,1})}$	$S^{3}_{4,2}(C^{3}_{4,2}, C^{4}_{5,2})$	
5	$S^{1}_{5,-1}(C^{1}_{5,-1}, C^{2}_{4,-1})$		$\boldsymbol{S^{3}_{5,1}(C^{3}_{5,1}, C^{4}_{6,1})}$	
⋮				

Table 3: Data Structure		
Time	Catch	Stock
1	$C^{1}_{3,1}$	$S^{1}_{3,1}(C^{1}_{3,1}, C^{2}_{4,1})$
2	$C^{2}_{3,2}$	$S^{2}_{3,2}(C^{2}_{3,2}, C^{3}_{4,2})$
⋮	⋮	⋮
35	$C^{35}_{3,35}$	$S^{35}_{3,35}(C^{35}_{3,35}, C^{36}_{4,35})$

Table 4: Within and Between Variation[a)] for Catch and Stock Size: Cod and Saithe		
	Within Variation	Between Variation
Cod		
Catch	0.80	1.66
Stock	0.82	1.75
Saithe		
Catch	1.08	1.48
Stock	1.04	1.62
[a)] Standard Deviation		

Table 5: Panel Stationarity Tests: Cod and Saithe[a)]

	LLC[b)]	Fisher[c)]
Cod		
Catch	-9.18 (0.00)[d)]	-7.4 (0.00)
Stock	-7.80 (0.00)	-7.70 (0.00)
Saithe		
Catch	-8.07 (0.00)	-3.11 (0.00)
Stock	-6.32 (0.00)	-2.36 (0.01)

[a] Null hypotheses is that all panels have unit root.
[b] LLC asymptotically normal without trend, lags chosen by AIC and each panel demeaned.
[c] Fisher inverse normal under the assumption that *t* approaches infinity.
[d] p-values in parentheses.

Table 6: Stock Elasticity: Cod and Saithe						
	Cod			Saithe		
	$\hat{b}$	$H_o: b = 0$	$H_o: b = 1$	$\hat{b}$	$H_o: b = 0$	$H_o: b = 1$
Overall	1.05	reject	not-reject	1.14	reject	not-reject
1977-1986	1.01	reject	not-reject	0.91	reject	reject
1987-1996	1.04	reject	not-reject	1.11	reject	not-reject
1997-2005	1.00	reject	not-reject	1.25	reject	not-reject
2006-2011	0.93	reject	not-reject	0.95	reject	not-reject

Appendix

Fixed Effects Within Regression, instrumental variable for stock, bootstrapped 1000 times.
Cod: Number of Groups 10, Number of time periods 35, Number of observations 350
Saithe: Number of Groups 13, Number of time periods 35, Number of observations 455
Corrected for clustered residuals by panel

	Cod			Saithe		
	Coefficient	Std. Error	p-value	Coefficient	Std. Error	p-value
Base	-0.981	0.200	0.00	-2.054	0.367	0.00
ivStock	1.057	0.041	0.00	1.146	0.105	0.00
1978	0.12	0.24	0.62	0.26	0.27	0.34
1979	-0.01	0.16	0.94	0.24	0.22	0.27
1980	-0.02	0.14	0.84	0.24	0.28	0.38
1981	-0.07	0.14	0.58	0.12	0.22	0.56
1982	-0.04	0.13	0.74	0.07	0.22	0.73
1983	0.14	0.13	0.27	0.34	0.24	0.15
1984	0.02	0.14	0.87	0.66	0.22	0.00
1985	-0.14	0.16	0.37	0.62	0.27	0.02
1986	0.10	0.14	0.45	0.59	0.34	0.08
1987	0.24	0.14	0.09	0.99	0.35	0.00
1988	0.27	0.16	0.10	0.89	0.58	0.12
1989	-0.01	0.17	0.96	0.54	0.46	0.23
1990	-0.46	0.17	0.01	0.85	0.27	0.00
1991	-0.82	0.22	0.00	0.85	0.42	0.04
1992	-0.54	0.16	0.01	0.97	0.33	0.00
1993	-0.38	0.17	0.02	0.36	0.34	0.28
1994	-0.04	0.13	0.73	0.60	0.30	0.04
1995	-0.02	0.13	0.84	0.15	0.39	0.69
1996	-0.11	0.18	0.56	0.83	0.41	0.04
1997	0.11	0.15	0.46	0.54	0.32	0.09
1998	0.24	0.14	0.09	0.54	0.28	0.05
1999	0.14	0.13	0.26	0.25	0.25	0.31
2000	0.11	0.13	0.40	-0.03	0.23	0.86
2001	-0.12	0.13	0.34	-0.14	0.25	0.59
2002	-0.26	0.15	0.09	-0.06	0.22	0.76
2003	-0.37	0.14	0.01	-0.00	0.23	0.98
2004	-0.09	0.13	0.49	0.14	0.25	0.54
2005	-0.12	0.15	0.39	0.08	0.24	0.71
2006	-0.27	0.16	0.09	0.45	0.27	0.10
2007	-0.52	0.14	0.00	0.36	0.27	0.18
2008	-0.80	0.13	0.00	0.36	0.23	0.11
2009	-0.93	0.17	0.00	0.28	0.20	0.16
2010	-0.92	0.18	0.00	0.13	0.22	0.55
2011	-0.96	0.21	0.00	0.20	0.22	0.34

Sigma_u	0.32	-	-	0.66	-	-
Sigma_e	0.33	-	-	0.76	-	-
R^2 between	0.98	-	-	0.96	-	-
R^2 within	0.83	-	-	0.54	-	-

Endnotes

[i] In this paper we use the phrase ‘catch’ and ‘landings’ interchangeably.

[ii] Our measure of fishing effort is narrowly defined in terms of removing fish from the sea. The activity of fishing, of course, is a complicated activity requiring the use of many factor inputs (Squires, 1987). As fish stocks are depleted and catch per unit of effort decreases, additional economic inputs would be required to maintain fishing effort.

[iii] See Squires (1987) for a detailed examination of fishing effort. Also, Kirkely *et al.,* (1998).

[iv] Of course, the numbers of fish must decline with each unit of fishing effort.

[v] See Gudmundsson (1994) and Fournier and Archibald (1982) for an interesting discussion using catch-at-age data.

[vi] Hannesson, 2013 uses ICES data in estimating a recruitment equation.

[vii] VPA uses assumptions on biological parameters and some current stock survey data to predict an initial stock level.

[viii] See Steinshamn (2011).

[ix] See, Jennings *et al*., (2001).

[x] The LLC test procedure is recommended for moderate-sized panels, with perhaps between 10 and 250 individuals and 25 to 250 observations per individual. These requirements are met for the data sets at hand. Furthermore, the LLC test requires that the panels be balanced.

[xi] Although the modelling procedure defines endogeneity in the VPA generated stock variable, it is worthwhile to statistically verify the problem. The Hausman test is a standard econometric procedure for testing endogeneity (see Wooldridge, 2002) but it is based on the assumption of full efficiency in the variance-covariance matrix in testing. The procedure is to use the predicted residuals from equation (6) as a regressor in equation (5). A test of no endogeneity is a null that the residual parameter is zero. Such testing generates p-values of 0.21 and 0.22 for cod and saithe, respectively. The statistical test supports rejection of the null of endogeneity.

[xii] See. Ekerhovd (2013).

Economists are interested in the relationship between fishing effort and stock size, and how these impacts catch levels. The interest lies in the stock elasticity where it is thought that for pelagic fish species it is close to zero and for demersal fish stocks closer to one. We statistically model and estimate the relationship between stock size and catch for two species, Northeast Arctic cod and saithe. In doing so we are able to recover estimates of stock elasticity but also estimates of catchability coefficients for different age classes and importantly an implicit index of fishing effort. Data on observed catch and a measure of biomass-at-age are available from the International Council for the Exploration of the Sea. The generated stock data are problematic and instrumental variables and bootstrapping are used in estimation. Time-series techniques applied to panel data are used to statistically motivate the estimation, which is carried out within a two-way panel framework.

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