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A Note on the "Stock Effect"

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Abstract

The “stock effect” implies that unit operating costs will be sensitive to the size of the exploited fish stock(s). This is investigated, using data for Norwegian trawlers. The results indicate that there is a significant stock effect for the two most important stocks exploited by these fisheries, haddock and cod jointly, and saithe. Two cost function specifications are used, one using catch shares as weights and another using a Taylor approximation to the cost function. While both agree on the existence of the stock effect, the numerical estimates of its strength differ.

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INTRODUCTION

All fisheries economists are familiar with the Schaefer production function $Y = qES$, and all have probably used it on innumerable occasions. They do so because it is mathematically convenient and not unreasonable, but all are probably aware that it implies a maximum "stock effect", making the catch per unit of effort proportional to the size of the exploited stock. This may often be close to being true, but not always. The stock effect is certainly not a theoretical curiosity; ever since Colin Clark's pioneering work (e.g., Clark [1976]) it has been recognized that a weak or nonexistent stock effect may have dire implications for the viability of exploited fish stocks in unregulated fisheries. Less dramatically, the stock effect is important for the profitability of fisheries and the target level of managed fish stocks.

Despite its importance, there are relatively few empirical investigations of the stock effect. According to Bjørndal (1987) the stock effect for North Sea herring is very weak, while Hannesson (1983) found a significant stock effect for the Lofoten cod fishery, although apparently less strong than implied by the Schaefer function. Recently, Sandberg (forthcoming) has investigated the stock effect for the Norwegian herring fisheries and the coastal cod fisheries. He found that the stock effect could vary not only between fish stocks but between gear types as well. The stock effect is weak or nonexistent for purse seine fishing for herring, but significant for coastal vessels. He explains this by a more restricted range of action for the latter. Nearshore fishing for cod has a weaker stock effect than offshore fishing with long liners, which he explains by coastal fishing concentrating on dense spawning migrations of the stock.

In this paper the stock effect in the Norwegian trawl fisheries will be examined. There are some reasons to expect the stock effect to be present in a bottom-trawl fishery. If the fish were always evenly distributed over a given area, we would be granted the maximal stock effect of the Schaefer function. But fish do not redistribute themselves instantaneously, and even for bottom-dwelling fish the distribution is likely to be somewhat patchy.[1] This we can in fact infer from fishermen's behavior; trawl skippers are known to spend significant time on searching for suitable aggregations of fish.

The approach will be similar to Sandberg's in that we will look at the impact of fish stock abundance on operating costs. If the stock effect is present, boats will spend less time filling their holds, or return half empty in case there is a dearth of fish. Either way the operating cost per unit of fish caught will be lower the more abundant the fish stock. Needless to say, fixed costs are irrelevant for this, and so are quasi-fixed costs such as insurance, which have to be paid whether or not the boat is used for a long or a short period of time or is making frequent or occasional trips.

THE DATA

The data to be used cover operating costs for Norwegian trawlers fishing for cod and similar types of fish 1990-2001[2]. Each year only a sample of boats is represented, and so we have an unbalanced panel with 574 observations in total. Excluding quasi-fixed costs, we are left with costs covering "ice, fuel, bait, and containers (fish boxes, etc.)."[3] These types of costs are the

[1] On this, see Coppola and Pascoe (1998).
[2] The data were obtained from the Norwegian Directorate of Fisheries.
[3] Labor costs are not included in operating costs, because the crew gets a share in the revenues from fishing.

ones most closely related to the length of a fishing trip. As these costs consist mainly of fuel, they have been deflated by a price index for fuels.[4]

The trawlers exploit a number of stocks, the most important being Northeast Arctic cod, Northeast Arctic haddock, Northeast Arctic saithe, and Greenland halibut. The share of these stocks in the total catch varies considerably over time, depending on the status of the stocks. The catches from these stocks are controlled by total catch quotas, in which the vessels have individual shares that vary from vessel to vessel. Data on stock abundance were taken from the 2005 report from the Northeast Arctic Working Group of ICES.[5]

The data on operating costs are annual, and so are the data on fish catches. Different types of fish are sometimes caught together, but usually it is possible to distinguish between areas where one type of fish is predominant, and so to a large extent they are caught separately. The main exceptions are Northeast Arctic cod and haddock, which often are caught together. This is partly reflected in a high correlation of catches from these stocks (Table 1), but this correlation is also due to the fact that the abundances of these stocks are highly correlated (Table 2), the total catch quotas being set on the basis of stock abundance. Because of this, we shall in the following consider the catches and the size of these two stocks jointly.

Table 1

Correlation matrix for catches from different stocks

	Cod	**Haddock**	**Saithe**	**Gr. halibut**	**Other**
Cod	1				
Haddock	.7314	1			
Saithe	.1397	.2315	1		
Gr. halibut	-.0537	-.0545	-.0299	1	
Other	.0098	.1076	.1767	.1789	1

Table 2

Correlation matrix for abundance of different stocks

	Cod	**Haddock**	**Saithe**	**Gr. halibut**
Cod	1			
Haddock	.8093	1		
Saithe	-.2622	.0515	1	
Gr. halibut	-.8833	-.6636	.4737	1

Three different types of trawlers are involved in these fisheries; small trawlers landing their fish fresh for onshore processing, fresh fish trawlers which also do so but are larger and go on longer trips, and factory trawlers that process the catch on board into fillets or round, frozen fish and which generally are larger than the fresh fish trawlers. The fresh fish trawlers have higher operating costs than the small trawlers because they go on longer trips and fish further offshore, and the factory trawlers have higher operating costs than the fresh fish trawlers because they process the catch onboard. These differences could be reflected in differences in the level of operating costs irrespective of the quantity fished; fishing further offshore would

[4] Statistics Norway, wholesale price index for fuels (*engroshandel med drivstoff og brensel*).
[5] ICES is the acronym for the International Council for the Exploration of the Seas, based in Copenhagen.

imply higher costs, and processing might do so as well, it being necessary to keep the freezing plant running irrespective of how much fish is in the hold. The cost per unit of fish caught could also be different for the said types of vessels; in particular one would expect the factory trawlers to have a higher cost per unit of fish caught than the other two, because of the processing involved. Finally, the operating costs can be expected to fall over time because of technological progress, and they may do so differently for the three different types of vessels.

MODEL SPECIFICATION AND RESULTS

As to the incorporation of the stock effect in the cost relationship to be estimated, two approaches will be taken, one based on landing shares and the other on a Taylor approximation to the cost function. The abundance of a particular stock will presumably have a stronger impact on the operating costs the higher the share of the catch from that stock in the total landings of fish. This leads to the following specification of the cost function:

(1) $$C_j = a_0 + d_j + \sum_{i=1}^{4} a_i Y_i + \sum_{i=1}^{4} a_{ij} d_j Y_i + \sum_{i=1}^{3} b_i y_i S_i + gt + g_j d_j t$$

where a_0 is operating cost independent of the quantity fished (Y), such as steaming between the fishing banks and landing places and costs of searching for suitable concentrations of fish, j denotes type of vessel (small, fresh fish, factory), d is a dummy variable for fresh fish or factory trawler, S is the size of a fish stock and is weighted by the share of the stock in total landings ($y_i = Y_i / \sum Y_j$), and t is time. While the unit cost may vary between types of trawlers (cf. the interaction term d_jY_i), the stock effect is assumed to be the same for all types of vessels. As there is no meaningful stock abundance variable for “other” fish, there are only three stock variables to be considered.

Alternatively we may take a first order Taylor approximation to the operating cost function:

(2) $$C = a_0 + f\left(S\right)Y$$

where $f(S)$ is the cost per unit of fish caught, presumably depending inversely on the abundance of the fish stock. Expanding this from $S = 0$ yields

(3) $$C = a_0 + f(S^*)Y + f'(S^*)YS = a_0 + a_1Y + bYS$$

where S^* is some intermediate stock level which gives a reasonable approximation without invoking higher order derivatives. This leads to the following function to be estimated:

(4) $$C_j = a_0 + d_j + \sum_{i=1}^{4} a_i Y_i + \sum_{i=1}^{4} a_{ij} d_j Y_i + \sum_{i=1}^{3} b_i Y_i S_i + gt + g_j d_j t$$

The results from linear regression of (1) and (4) are shown in Table 3. Equation (1) produces a significantly negative stock effect for cod and haddock combined and for saithe as well, but not for Greenland halibut. Equation (4) produces a significantly negative stock effect only for cod and haddock combined. The results for the two dummies show higher quantity-independent operating costs for fresh fish trawlers than for small trawlers, and higher for factory trawlers than for fresh fish trawlers, as expected.

Table 3

Regression results for (1) and (4). Numbers in parentheses show t-values. **(*) denotes significance at the 1% (5%) level

Specification	Catch shares (Equation 1)	Taylor approximation (Eq. 4)
a_0	677335 (2.67**)	52444 (.24)
d (fresh)	878543 (3.26**)	958229 (3.63**)
d (factory)	3595362 (11.39**)	3834380 (12.18**)
a (cod & haddock)	.9412 (4.99**)	1.0095 (5.19**)
- interaction fresh	-.6164 (-3.50**)	-.5921 (-3.32**)
- interaction factory	-.5948 (-3.33**)	-.5125 (-2.92**)
a (saithe)	.6030 (4.23**)	.5785 (2.93**)
- interaction fresh	-.4177 (-3.17**)	-.4012 (-3.04**)
- interaction factory	-.1103 (-.80)	-.0863 (-0.63)
a (Gr. halibut)	2.5540 (3.02**)	3.0254 (1.86)
- interaction fresh	-.9448 (-1.20)	-1.0815 (-1.34)
- interaction factory	-2.0920 (-2.55*)	-2.4700 (-2.96**)
a (other)	-.1910 (-1.80)	.0701 (0.80)
- interaction fresh	1.0094 (8.07**)	1.0084 (8.11**)
- interaction factory	.4969 (4.49**)	.3227 (3.14**)
b (cod & haddock)	-.4244 (-3.39**)	-1.02E-07 (-1.98*)
b (saithe)	-1.6637 (-2.70**)	-1.92E-07 (-0.71)
b (Gr. halibut)	1.8774 (0.13)	1.08E-06 (0.06)
Time	62344 (2.49*)	57278 (2.32*)
- interaction fresh	-77880 (-2.95**)	-87012 (-3.25**)
- interaction factory	-215011 (-7.53)	-226686 (-7.88**)
R^2 (adjusted)	.8730	.8694

Other results are less satisfactory. Operating costs are increasing over time for small trawlers, but falling for the two other types. The interaction terms show lower quantity-dependent costs for factory trawlers than for small trawlers for all types of fish considered except “other”. This is contrary to expectation. Furthermore, the quantity-dependent cost for “other” is negative or extremely low for small trawlers. Hence neither of these equations succeeds in estimating the quantity-dependent costs for the four types of fish identified. We look, therefore, also at the case where the cost per unit of fish caught is assumed to be the same for all types of fish, in which case the first two sums in Equations (1) and (4) collapse into just one term each, retaining the stock effect for all three species.

The results from using total catch in Equations (1) and (4) rather than the catch of the four different types of fish are shown in Table 4. The unexpected sign of the interaction terms with the total catch has disappeared; the term shows higher unit costs for fresh fish trawlers than for small trawlers, and higher still for factory trawlers, but the coefficients are insignificant, however. The stock effect is negative and significant for cod and haddock together, and for saithe as well (but insignificant for saithe in Equation 4). The new and surprising result is that the stock effect for Greenland halibut is significantly positive.[6]

[6] Weninger (1998) also found a coefficient of the wrong sign in his analysis of the surf clam fishery, but it was not significantly different from zero. His focus was not on the stock effect, however.

Table 4

Regression results for (3) and (4) with total catch. Numbers in parentheses show t-values. **(*) denotes significance at the 1% (5%) level.

Specification	**Catch shares (Equation 1)**	**Taylor approximation (Eq. 4)**
a_0	1188355 (4.82**)	562286 (2.57*)
d (fresh)	185862 (0.68)	509710 (1.87)
d (factory)	2759189 (8.69**)	2884849 (8.91**)
a_1 (all fish)	.2894 (4.38**)	.4054 (5.57**)
- interaction fresh	.1317 (1.58)	.0773 (0.91)
- interaction factory	.0975 (1.28)	.0762 (0.96)
b (cod & haddock)	-.3977 (-5.96**)	-9.7E-08 (-4.73**)
b (saithe)	-1.1139 (-3.52**)	-1.88E-07 (-1.79)
b (Gr. halibut)	34.90 (6.25**)	1.79E5 (6.86**)
Time	5986 (0.28)	19640 (0.89)
- interaction fresh	-22930 (-0.91)	-55048 (-2.18*)
- interaction factory	-152150 (-5.70**)	-162539 (-5.99**)
R^2	.8501	.8435

Table 5

Regression results for (3) and (4) with total catch. Numbers in parentheses show t-values. **(*) denotes significance at the 1% (5%) level

Specification	**Catch shares (Equation 1)**	**Taylor approximation (Eq. 4)**
a_0	1456941 (5.81**)	601127 (2.64**)
d (fresh)	501998 (1.80)	760358 (2.70)
d (factory)	2754228 (8.39**)	3032845 (9.03**)
a_1 (all fish)	.2867 (4.20**)	.4775 (6.37**)
- interaction fresh	.0750 (0.88)	.0329 (0.37)
- interaction factory	.0964 (1.22)	.0540 (0.65)
b (cod & haddock)	-.5231 (-7.96**)	-1.26E-07 (-5.99**)
b (saithe)	-1.5688 (-4.92**)	-3.33E-07 (-3.11)
Time	-2988 (-0.13)	11468 (0.50)
- interaction fresh	-39428 (-1.52)	-69975 (-2.67**)
- interaction factory	-147942 (-5.37**)	-167864 (-5.95**)
R^2	.8400	.8307

This surprising result for Greenland halibut can be explained by the high and negative correlation between the stock of Greenland halibut and the stocks of cod and haddock. If the stock of Greenland halibut is removed from the regressions and included in "other" we get the results in Table 5. The stock effect is now significantly negative both for cod and haddock jointly and for saithe, in both regressions. The fresh fish trawlers have higher quantity-independent operating costs than the small trawlers and the factory trawlers higher still. The interaction terms point in the same direction for the unit costs of fish, but these terms are not significant. All significant terms involving time show falling operating costs over time.

What about the strength of the stock effect? Tables 6 and 7 illustrate this, using the results in Table 5, for a stock increase of 0.5 million tonnes for cod and haddock jointly and saithe. This is not an unusual variation; in 1990 the cod stock was just below one million tonnes while a year later it had grown to 1.5 million tonnes. The saithe stock was 250,000 tonnes in 1990 and 760,000 in 1995. Using Equation (1), the change in operating cost due to a change ΔS in the stock, is

$$\Delta C = by\Delta S$$

while for Equation (4) it is

$$\Delta C = bY\Delta S$$

Table 6

Change in operating costs (excl. quasi-fixed) due to a stock increase of 0.5 million tonnes for cod & haddock and saithe, using Equation (1).

	Coefficient	Share	Change op. cost	Operating cost	Change %
			Cod&haddock		
Small	-0.5231	0.2157	-56405.6	2163824	-2.6
Fresh	-0.5231	0.5238	-137001	2311167	-5.9
Factory	-0.5231	0.3050	-79783.5	5918181	-1.3
			Saithe		
Small	-1.5688	0.1423	-111643	2163824	-5.2
Fresh	-1.5688	0.2154	-168996	2311167	-7.3
Factory	-1.5688	0.1533	-120272	5918181	-2.0

Table 7

Change in operating costs (excl. quasi-fixed) due to a stock increase of 0.5 million tonnes for cod & haddock and saithe, using Equation (4).

	Coefficient	Catch	Change op. cost	Operating cost	Change %
			Cod&haddock		
Small	-1.26E-07	469668.9	-295891	2163824	-13.7
Fresh	-1.26E-07	1010462	-636591	2311167	-27.5
Factory	-1.26E-07	1087775	-685298	5918181	-11.6
			Saithe		
Small	-3.33E-07	309968.8	-516098	2163824	-23.9
Fresh	-3.33E-07	415615.1	-691999	2311167	-29.9
Factory	-3.33E-07	546772.8	-910377	5918181	-15.4

In Tables 6 and 7 these changes are related to the average operating costs (excl. quasi-fixed costs) in 2001, for the three trawler groups, using average catch shares and catches per vessel in 2001.[7] There is considerable difference between these results; using Equation (1), where the catches from each stock are used as weights, gives almost trivially small gains from building up fish stocks, while the Taylor expansion (Equation 4) gives significant gains of the order of 10 - 30 percent of the costs, depending on which stock and which group of trawlers we are looking at. We are inclined to think that the Taylor expansion gives a more correct picture of the importance of the stock effect, as it is methodologically less ad hoc than using shares.

CONCLUSION

The stock effect, sensible as it may appear, is elusive. There are a number of reasons for this. Boats catch fish from different stocks within the time frame the data on their catches and costs usually refer to, making it difficult to relate their activities to one particular stock. Boat captains do not fish at random but search for concentrations of fish. Such “patchy” distributions in and of themselves dilute the stock effect. Finally, stock assessment is not an exact science, and errors in stock assessment may mask the existence or strength of the stock effect. For all these reasons it is difficult to estimate the stock effect with a high level of precision.

This paper has demonstrated the presence of a stock effect in the Norwegian bottom trawl fishery, confirming what often is presumed about such fisheries. The numerical results do not agree on the strength of the stock effect, but there are indications that it is decidedly non-trivial; a moderate build-up of the stocks of cod and saithe from the low levels they had fallen to around 1990 might have saved the industry 10 - 30 percent of the operating costs directly associated with catching fish. This strengthens the case for setting a relatively high target level of these stocks otherwise argued on the basis of precautionary motives.

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[7] In 2001 the cod stock was 1.4 million tonnes, but reached 2.3 million tonnes in 1997 and was 1.9 million tonnes in 1992, and so we are looking at cost savings from rebuilding the stock to its 1992 level. The saithe stock was 950,000 tonnes in 2001 and has seldom exceeded one million tonnes. Therefore it is doubtful whether it could be increased by 500,000 tonnes from its 2001 level, and so the example would show a cost increase due to a possible decline in the stock.

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