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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. The effect on operating costs is relatively small, although substantial if it is related to costs directly attributable to the stock under consideration.*

Key words Fisheries economics, stock effect.

JEL Classification Code Q22.

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 (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 optimum 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 (2006) 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

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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 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 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, 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 ones most closely related to the number of fishing trips and their duration. As these costs consist mainly of fuel, they have been deflated by a price index for fuels.[4] The quasi-fixed operating costs are insurance, maintenance, and a category labelled "miscellaneous." The variable operating costs vary between 10 and 50% of total operating costs (excluding labor costs) and are, on average, just below 30%. There is a significant correlation between this share and the number of operating days reported, but the latter explains only about 20% of the variation in the said share.

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, 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 catch and the size of these two stocks jointly.

Three different types of trawlers are involved in these fisheries: small trawlers landing fish fresh for onshore processing, fresh fish trawlers which also do so but are larger and take longer trips, and factory trawlers that process the catch on board

[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 of the revenues from fishing instead of a fixed wage.
[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.

Table 1
Correlation Matrix for Catches from Different Stocks

	Cod	Haddock	Saithe	Gr. Halibut	Other
Cod	1				
Haddock	0.7314	1			
Saithe	0.1397	0.2315	1		
Gr. Halibut	–0.0537	–0.0545	–0.0299	1	
Other	0.0098	0.1076	0.1767	0.1789	1

Table 2
Correlation Matrix for Abundance of Different Stocks

	Cod	Haddock	Saithe	Gr. Halibut
Cod	1			
Haddock	0.8093	1		
Saithe	–0.2622	0.0515	1	
Gr. Halibut	–0.8833	–0.6636	0.4737	1

into frozen fillets and generally are larger than the fresh fish trawlers. The fresh fish trawlers have higher operating costs than the small trawlers because they take longer trips and fish further offshore. The factory trawlers have higher operating costs than the fresh fish trawlers because they process the catch onboard. These differences should be reflected in differences in the level of operating costs irrespective of the quantity fished; fishing further offshore would 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. While the latter is theoretically more appealing, there are problems with estimating it, as will be discussed below. A first-order Taylor approximation to the operating cost function gives:

$$C = a_0 + f(S)Y, \tag{1}$$

where $f(S)$ is the cost per unit of fish caught (exclusive of the quantity-independent term a_0), presumably depending inversely on the abundance of the fish stock. Expanding this from $S = 0$ yields:

$$C = a_0 + f(S^*)Y + f'(S^*)YS = a_0 + a_1Y + bYS, \qquad (2)$$

where S^* is some intermediate stock level which gives a reasonable approximation without invoking higher order derivatives. Allowing for catches from more than one stock and adding vessel group dummies and a time term, we get the equation to be estimated:

$$C_{kt} = a_0 + c_jd_j + \sum_{i=1}^{4} a_iY_{ikt} + \sum_{i=1}^{3} b_iY_{ikt}S_{it} + gt + \upsilon_k + \varepsilon_{kt}, \qquad (3)$$

where k indexes the vessel and t time. There are two main explanatory variables, Y_{ikt}, the amount of fish from stock i caught by vessel k in year t, and S_{it}, the size of stock i in year t. The latter variable is multiplied by the catch quantity variable, which causes problems, as Y_{ikt} and the product $Y_{ikt}S_{it}$ are highly correlated.[6] The stock effect is assumed to be qualitatively the same for all vessels, in the sense that they are all characterized by the same b_i, as all apply a similar fishing technology (bottom trawl). As there is no meaningful stock abundance variable for "other" fish, there are only three stock variables to be considered.

The constant a_0 reflects operating costs that are independent of the quantity fished, such as steaming between the fishing banks and the landing places and costs of searching for suitable concentrations of fish. The variable d_j is a dummy variable for fresh fish or factory trawler, allowing for the aforementioned differences in the levels of operating costs for the three different types of vessels. The time term (t) takes into account technological progress, which would lead to a decline in operating costs, all else equal. Finally there are two random elements, υ_k, which is vessel-specific, and ε_{kt}.

To get around the problems caused by the high correlation between Y_{ikt} and $Y_{ikt}S_{it}$, we shall use catch share y_{ikt} ($y_{ikt} = Y_{ikt}/\Sigma_iY_{ikt}$) instead of Y_{ikt}. The correlation between Y_{ikt} and $y_{ikt}S_{it}$ is much lower than between Y_{ikt} and $Y_{ikt}S_{it}$.[7] This specification, while being somewhat *ad hoc*, has the desirable property that the stock effect becomes more important for the costs the greater the share of the catch coming from the stock under consideration. The equation to be estimated then becomes:

$$C_{kt} = a_0 + c_jd_j + \sum_{i=1}^{4} a_iY_{ikt} + \sum_{i=1}^{3} b_iy_{ikt}S_{it} + gt + \upsilon_k + \varepsilon_{kt}. \qquad (4)$$

Equations (3) and (4) were estimated by panel methods, allowing for random effects and first order autocorrelation of residuals.[8] The results, reported in table 3, are qualitatively as expected. A significant portion of the operating costs are independent of the quantity caught. This element is significantly higher for the large fresh fish trawlers than the small ones,[9] and the factory trawlers have a higher constant element still, for reasons already discussed. The effect of quantity caught on costs is positive for all species and significant in all cases except one. The effect of time is significantly negative, indicating technological progress. For equation (4) the stock effect is significant and negative for cod and haddock combined and for saithe as well, but insignificant and positive for Greenland halibut. For equation (3) the stock

[6] The correlation coefficient for Y and YS is over 0.9 for all three species. This high correlation is, in part, caused by fact that the catch quota from a stock is based on assessment of stock abundance.
[7] For cod/haddock and saithe it is around 0.6, while for Greenland halibut it is high (0.9).
[8] The Stata xtregar routine was used.
[9] The dummy d (fresh) refers to the large fresh fish trawlers.

effect is not significant for any of the species, which may be due to the high correlation between catch and the product of catch and stock discussed above.

It is possible that the sensitivity of costs to the quantity caught differs between the types of vessels studied. In particular, one would expect the factory trawlers to have higher unit costs because of the processing involved. It is also possible that technological progress varies between the different categories of boats. Attempts to include interaction between the type of vessel and quantity caught and time were unsuccessful; the coefficients of the interaction terms had an unexpected sign and were mostly insignificant.

What about the strength of the stock effect? Tables 4 and 5 illustrate this, using the results in table 3, 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 (3), the change in operating cost due to a change ΔS in the stock is:

$$\Delta C = bY\Delta S, \tag{5}$$

while for equation (4) it is:

$$\Delta C = by\Delta S. \tag{6}$$

In tables 4 and 5 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.[10] Both the Taylor expansion (equation [3]) and the

Table 3

Regression Results for Equations (3) and (4)

	Catch Shares (4)	Taylor Approximation (3)
a_0	1,524,280 (9.18**)	1,111,642 (7.59**)
c (Fresh)	359,212 (3.38**)	333,437 (3.10**)
c (Factory)	2,083,302 (13.63**)	2,137,317 (13.58**)
a (Cod & Haddock)	0.2678 (4.33**)	0.3286 (2.81**)
a (Saithe)	0.4194 (4.33**)	0.3751 (2.20*)
a (Greenland Halibut)	1.2481 (3.41**)	0.8281 (0.66)
a (Other)	0.3510 (6.67**)	0.4578 (9.89**)
b (Cod & Haddock)	–0.3815 (–3.56**)	–7.41E–08 (–1.56)
b (Saithe)	–1.2129 (–2.12*)	–5.21E–08 (–0.21)
b (Greenland Halibut)	0.4834 (0.05)	8.98E–06 (0.51)
t	–56,897 (–4.62**)	–67,222 (–5.01**)
R^2	0.84	0.83

Notes: Numbers in parentheses show z-values.
**(*) denotes significance at the 1% (5%) level.

[10] 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, 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, so the example would show a cost increase due to a possible decline in the stock.

catch share approach (equation [4]) indicate that rebuilding fish stocks has a rather small effect on the operating costs. Since equation (3) did not produce significant *b*-coefficients, there is some reason to pay greater attention to the results obtained with equation (4). According to this, the said stock rebuilding would reduce operating costs by 1–6%, varying between vessel groups and fish stocks. Note, however, that a large part of the operating costs appears to be independent of the catch volume and the stock abundance. If we adjust for this and relate the cost savings to the catch-dependent costs attributable to each stock, we get the results in the last column in tables 4 and 5.[11] According to the results in table 5, this produces substantial cost savings, a rebuilding of the cod stock would reduce the costs attributable to cod by around 15% for the fresh fish trawlers (large and small), but only by 6% for the factory trawlers. The effect on catches of saithe is greater; a decline of the saithe stock[12] would raise the saithe-related costs by about 50% for the fresh fish trawlers and by about 20% for the factory trawlers.

Table 4
Change in Operating Costs (excl. Quasi-Fixed) Due to a Stock Increase of 0.5 Million Tonnes for Cod & Haddock and Saithe (according to Equation [5])

	b	Catch	Change Op. Cost	Operating Cost	Change %	Adjusted Change %
Cod & Haddock						
Small	–7.41E–08	469,668.9	–17401	2,163,824	–0.8	–4.5
Fresh	–7.41E–08	1,010,462	–37437	2,311,167	–1.6	–4.5
Factory	–7.41E–08	1,087,775	–40302	5,918,181	–0.7	–3.9
Saithe						
Small	–5.21E–08	309,968.8	–8075	2,163,824	–0.4	–3.2
Fresh	–5.21E–08	415,615.1	–10827	2,311,167	–0.5	–5.8
Factory	–5.21E–08	546,772.8	–14243	5,918,181	–0.2	–2.7

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 timeframe 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.

[11] The costs attributable to each stock are obtained by subtracting $a_0 + c_j d_j + 11g$ from the operating costs in 2001 and multiplying the remainder by the share of cod and haddock versus saithe in the catches in 2001 (table 5).
[12] The saithe stock was quite large in 2001 (cf. footnote 10), and a decline from this level is more likely than the opposite and could occur for natural reasons.

Table 5
Change in Operating Costs (excl. Quasi-Fixed) due to a Stock Increase of 0.5 Million Tonnes for Cod & Haddock and Saithe (according to Equation [6])

	b	Share	Change Op. Cost	Operating Cost	Change %	Adjusted Change %
Cod & Haddock						
Small	–0.3510	0.2157	–37,855	2,163,824	–1.8	–13.9
Fresh	–0.3510	0.5238	–91,927	2,311,167	–3.4	–16.7
Factory	–0.3510	0.3050	–53,528	5,918,181	–0.9	–5.9
Saithe						
Small	–1.2129	0.1423	–86,298	2,163,824	–4.0	–47.9
Fresh	–1.2129	0.2154	–130,629	2,311,167	–5.7	–57.6
Factory	–1.2129	0.1533	–92,969	5,918,181	–1.6	–20.3

This paper has demonstrated the presence of a stock effect in the Norwegian bottom trawl fishery, confirming what often is presumed about such fisheries. In relation to operating costs it is rather small; the results indicate that a moderate buildup of the stocks of cod and saithe from the low levels they had fallen to around 1990 might have saved the industry 1–6% of the operating costs. Looking at the costs directly attributable to each fish stock, these savings are more substantial, 5–50%, depending on which stock and what type of vessel we are looking at. This strengthens the case for setting a relatively high target level for these stocks, otherwise argued on the basis of precautionary motives. However, while the impact of the stock effect on costs that are directly related to catching fish from a particular stock may be substantial, it need not be very large in relation to total costs. Catch-related operating costs need not be a very large share of total costs; a large part of total operating costs is unrelated to fish catch (steaming costs, operating costs independent of fishing trips). In addition, there is capital cost, which for large and capital-intensive vessels, is a significant part of total costs.

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