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Capital Dynamics in the North Sea Herring Fishery

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Abstract *Dynamic adjustment is an integral part of natural resource economics. Commonly, capital is assumed to respond instantaneously to changes in profits, while in reality adjustment may take place only with a time lag. In this paper, an empirical analysis of capital (boat) dynamics in the North Sea herring fishery is undertaken. A discrete time model is formulated to model decisions of boats to enter or exit the fishery. A lagged model is specified to reflect adjustment time to changes in profits. The empirical results indicate that fleet adjustment in this fishery primarily depends on current period profits and that the opportunity cost may depend on returns in the alternative fishery. Inclusion of lagged variables to account for the construction time for new boats, showed only a small improvement in the statistical fit. Moreover, the results did not support a hypothesis that entry in response to positive profits is more elastic than exit due to negative profits.*

Introduction

Dynamic adjustment is an integral part of natural resource economics. Most economic models are formulated in continuous time as a system of differential equations. Both natural and man-made capital is commonly assumed to respond instantaneously to changes in, e.g., harvesting and profitability conditions. An example of this type of model is given by the Gordon-Schaefer bioeconomic model (Clark 1976). In real life, these assumptions are not likely to hold. Once a piece of capital is committed to a fishery, the owner may be reluctant to transfer to another fishery in the short run due to non-negligible transfer costs. Accordingly, adjustment to changes in profitability conditions may take place only with a time lag. For renewable resources, natural growth may occur at discrete time intervals (seasonal growth), while recruitment commonly takes place with a time lag. Hence, for both types of capital stocks one is led to consider discrete time models, possibly with a lag structure, so that a difference equation model is called for rather than a differential equation model.

The purpose of this paper is to undertake an empirical analysis of capital (boat) dynamics in the North Sea herring fishery, based on data for the 1963–77 period. A discrete time model will be formulated to model decisions of boats to enter or exit the fishery. Secondly, a lagged model will be specified to reflect adjustment time to changes in profitability conditions. Although a number of papers analyze models of population dynamics by means of delay-difference equations (Clark 1976a; Deriso 1980; Bjørndal 1985), the empirical literature on capital (boat) dynamics is more scant.

The present analysis poses a number of econometric problems. The instantaneous adjustment models commonly assumed in theoretical analyses, specifying perfect mobility of capital, are hardly appropriate for the type of fishery we are dealing with. However, specifying the "correct" model is nontrivial and misspecification bias can be a potential problem. Secondly, estimating such models requires price, cost, and effort data, which in many instances may not be available.

In the following section, we shall give a brief description of the North Sea herring fishery. Alternative models of capital dynamics will be specified and estimated. The paper concludes with some recommendations for estimating equations for capital dynamics in resource models.

The North Sea Herring Fishery

The North Sea herring fishery takes place in the central and northern North Sea, with the main season in the months May to September. In the present case study, data for the Norwegian purse seine fleet will be used. The fishery, utilizing this technology, started in 1963. In the middle of the 1970s, however, the stock was severely depleted under an open access regime and the fishery was closed at the

Table 1
The North Sea Herring Fishery 1963–77

Year	Stock Size 1,000 Tons	Norwegian Harvest Tons	Number of Participating Norwegian Purse Seiners
1963	2,325	3,454	8
1964	2,529	147,933	121
1965	2,348	586,318	209
1966	1,871	448,511	298
1967	1,434	334,449	319
1968	1,056	286,198	352
1969	696	134,886	253
1970	717	220,854	201
1971	501	210,733	230
1972	509	136,969	203
1973	521	135,338	153
1974	345	66,236	165
1975	259	34,221	102
1976	276	33,057	92
1977	166	3,911	24

Source: Bjorndal (1987).

end of 1977. Regulations have been in effect ever since so as to allow the stock to recover. Table 1 contains estimates of stock size, Norwegian harvest and Norwegian purse seiners in the fishery for the period 1963–77.

An important characteristic of North Sea herring, as of other clupeids, is their schooling behavior. Schooling takes place to reduce the effectiveness of predators (Partridge 1982). Moreover, schooling fish contract their feeding and spawning range as the stock is reduced, with the size of schools often remaining unchanged. This behavior has permitted the development of very effective means of harvesting, especially the purse seine. With modern fish-finding equipment, harvesting can be profitable even at low stock levels. For these reasons, changes in stock size may have little effect on harvest quantity. In the extreme, constant effort may produce a constant harvest regardless of stock size (Murphy 1977; Ulltang 1980; Clark 1982). Hence, open access may cause severe stock depletion as evidenced by the collapse of a number of fisheries based on the harvest of schooling species (Bjørndal and Conrad 1987).

Figure 1, which is a state-space diagram showing combinations of fleet participation and stock size for the period 1963–77 (cf. Table 1), helps to illustrate

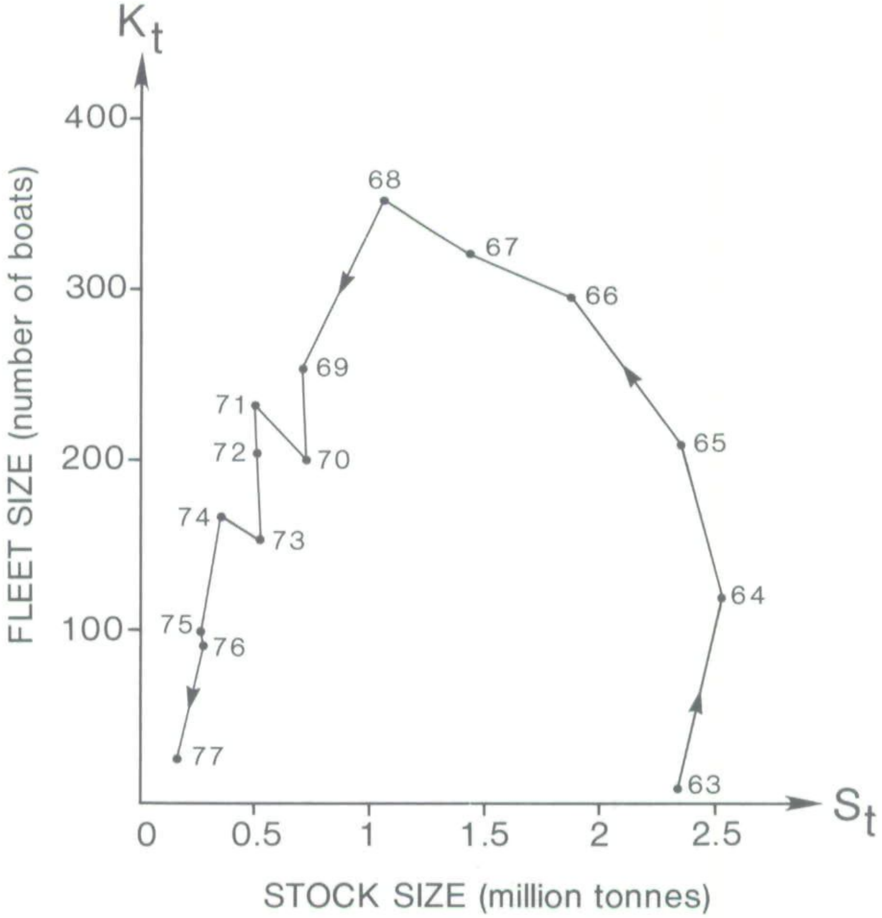

Figure 1. Stock Size and Norwegian Fleet Participation in the North Sea Herring Fishery.

the dynamics of the fishery. The early years of this fishery (1963–68) were characterized by increasing fleet participation and decreasing stock size. Since the stock initially was at a fairly high level, this period may represent "mining" of the resource. However, the situation changed in 1968, with generally decreasing fleet participation and stock size in the ensuing years. Presumably the declining stock caused a decrease in profits, which led some boats to exit from the industry. Nevertheless, profits were sufficient for the remaining boats.

Wilen (1976) analyzed common property exploitation of North Pacific fur seal. This industry went through a dynamic process similar in part to the one illustrated in Figure 1. However, exit from the industry allowed the stock to recover, and the data illustrated that a stable bionomic equilibrium was being approached. For North Sea herring, on the other hand, exit from the industry in the post-1968 period did not reduce harvest sufficiently to allow the stock to recover.

Cost and price figures for the 1963–77 period are given in Table 2. Operating costs per boat day (c_t) include variable costs, mainly fuel. Fixed and opportunity costs per boat per season (f_t) include interest payments, depreciation, maintenance, insurance, and an estimate of opportunity costs. Both cost figures rose substantially in the 1970s. Despite nominal cost increases, however, the price-cost ratio (p_t/c_t) was generally increasing from 1972. Growing stock scarcity with corresponding reductions in harvest (cf. Table 1) caused increases in price that exceeded cost increases. An increase in the real price of herring will, *ceteris*

Table 2

Costs and Herring Price (per ton). Figures in Norwegian Kroner (NOK).

Year	Operating Costs per Boat Day c_t	Fixed and Opportunity Costs per Season f_t	p_t[a]
1963	398	166,500	387
1964	414	171,000	339
1965	406	174,400	342
1966	406	176,700	357
1967	433	178,900	235
1968	445	180,100	213
1969	430	189,400	309
1970	572	243,500	437
1971	933	326,900	408
1972	1,019	394,200	358
1973	1,143	497,200	640
1974	1,574	591,800	830
1975	1,698	454,700	1,226
1976	2,444	575,000	1,422
1977	2,840	686,600	2,359

[a] All figures are in nominal Norwegian kroner (NOK). In the regressions, price figures will have to be adjusted by a factor of 0.6, which represents the boat owner's share of income. Cost figures only cover costs incurred by the boat owner.

Sources: p_t: The Directorate of Fisheries, Norway

c_t and f_t: The Budget Committee for the Fishing Industry, Norway.

paribus, improve profitability and attract new vessels or slow exit. As noted above, the declining stock level worked in the opposite direction by decreasing profitability and thus causing exit from the fishery. On balance, however, the net effect was for exit from the industry after 1968.

We will assume an industry production function

$$H_t = H(E_t, S_t, K_t) \tag{1}$$

where H_t is harvest in year t, E_t is fishing "effort" measured as the number of boat days, S_t is stock size at the beginning of year t, while K_t is the number of boats participating in the fishery. The reason for including the latter variable in the production function is the presence of external economies associated with the number of boats in the fishery (Bjørndal 1987).

We proceed to define industry profit (net revenues) in year t as

$$\Pi_t = p_t H(\cdot) - c_t E_t - f_t K_t \tag{2}$$

where p_t, c_t, and f_t are the per unit price of output, effort cost per boat day, and fixed cost per vessel, respectively. Once a boat is committed to the fishery, a certain fixed cost (f_t) is incurred. In the long run, boat owners will need to cover all costs. In the short run, fixed costs are irrelevant, and only variable costs are relevant. There is, however, some ambiguity with respect to the relevance of short run quasi-fixed costs such as set-up and transfer costs. This would call for alternative cost specifications in the empirical work to be undertaken below. The amount of variable costs ($c_t E_t$) will depend on the intensity of fleet participation (E_t). Prices may vary over time, but are assumed constant in a given season (year). Moreover, it is implicitly assumed that all boats are identical.

In the standard fisheries model, it is postulated that the existence of aggregate profits will entice entry to the fishery (Gordon 1954; Scott 1955; Smith 1968):

$$\dot{K} = n\Pi \tag{3}$$

Here, n is an adjustment parameter, indicating how quickly entry (exit) responds to the existence of positive (negative) profits. In the discrete time model, the adjustment equation becomes

$$K_{t+1} - K_t = n\Pi_t \tag{4}$$

With n positive it will be the case that (a) $K_{t+1} > K_t$ if $\Pi_t > 0$, (b) $K_{t+1} < K_t$ if $\Pi_t < 0$, and (c) $K_{t+1} = K_t$ if $\Pi_t = 0$. In this formulation, a simple linear adjustment function is assumed. Other alternatives will be considered below.

It is possible that the rates of entry and exit may differ, so that n^+ will apply in case of entry to the fishery, i.e., $\Pi_t > 0$, and n^- will apply in case of exit from the fishery, i.e., $\Pi_t < 0$. In general, one would expect $n^+ \geqslant n^-$, i.e., entry in response to positive profits is more elastic than exit due to negative profits (Clark, Clarke and Munro 1979). This will be tested for below by specifying and estimating an asymetric adjustment function.

For the North Sea herring fishery, we have used number of participating boats as our measure of capital. All purse seiners in the fishery employ the same harvesting techniques and the same equipment for electronic search such as echo-sounder and sonar. Although a capital deepening has taken place over the data period, the technology for search and catch has remained unchanged.

Vessel dynamics are assumed to occur according to

$$K_{t+1} - K_t = n\frac{(\Pi_t/p_t)}{K_t} \tag{5}$$

i.e., entry or exit will depend on normalized (real) profits per boat. The unit of n is vessels per Norwegian krone (NOK). For the empirical analysis, we use the net revenue function to rewrite Equation 5 as follows:

$$n\frac{(\Pi_t/p_t)}{K_t} = n\left[\frac{H_t - \frac{c_t}{p_t}E_t - \frac{f_t}{p_t}K_t}{K_t}\right]$$

Initially, the following four models were specified:

$$K_{t+1} - K_t = n\left[\frac{H_t - \frac{c_t}{p_t}E_t - \frac{f_t}{p_t}K_t}{K_t}\right] \tag{I}$$

$$K_{t+1} - K_t = n\left[\frac{H_t - \frac{c_t}{p_t}E_t}{K_t}\right], \; f_t = 0 \;\forall\, t \tag{II}$$

$$K_{t+1} - K_t = n\left[\frac{H_t - \frac{c_t}{p_t}E_t}{K_t}\right] + nf\left(\frac{1}{p_t}\right), \; f_t = \bar{f} \;\forall\, t, \tag{III}$$

$$K_{t+1} - K_t = n\left[\frac{H_t - \frac{c_t}{p_t}E_t}{K_t}\right] + n_3\left(\frac{p_{M,t}}{p_t}\right) \tag{IV}$$

Model I represents our basic hypothesis about fleet adjustment. However, as noted above, boat owners may in a given season consider fixed costs as "sunk." This is taken into consideration in the other model specifications. In Model II, the fixed cost is set equal to zero, while Model III assumes a constant f_t over time. Model IV assumes that fixed costs are sunk but that the vessel has an opportunity cost approximated by the price of mackerel, where $p_{M,t}/p_t$ is the relative price of mackerel to herring. This variable has been specified, since fishing mackerel for parts of the season may be considered an alternative to herring. *A priori* one would expect fleet participation in the herring fishery to decline when the real price of mackerel increases, i.e., the expected sign of n_3 is negative.

For the empirical analysis, we have used the data set as reported in Tables 1 and 2. Time periods correspond to seasons (years). Error terms have been appended to the estimating equations. The results are reported in Table 3. All regres-

Table 3
Estimation of Capital Dynamics Equation for the Period 1963–77[a]

Regression	n	nf	n_3	Derived f NOK	r^2	$\bar{r}^2$	DW	Method[b]
I	0.0871** (4.36)	—	—	—	0.58	0.58	2.04	OLS
II	0.0476* (1.58)	—	—	—	0.24	0.24	2.12	AUTO
III	0.1085** (3.52)	−20,945.0** (−3.05)	—	193,041	0.50	0.46	1.96	OLS
IV	0.1187* (3.93)	—	−239.28** (−3.40)	—	0.56	0.52	2.28	OLS

[a] The observation for 1963 has been excluded from the regressions. As this is the year the fishery started, this observation is believed to be not very representative for the dynamics of the fishery.
t statistics in parenthesis.
* denotes significance at the 90% level.
** denotes significance at the 95% level.
[b] OLS denotes ordinary least squares. AUTO means corrected for first order autocorrelation (Cochrane-Orcutt procedure).

sion lines have been estimated without an intercept term, which corresponds to the theoretical models.

The results in Table 3 show that the explanatory power of the alternative models varies. However, taking the fairly small sample size into account, regressions I, III, and IV provide reasonably good fits of the underlying functions measured in terms of r^2. In addition, in these three models all point estimates of n are highly significant and lie in the range 0.09–0.12. Moreover, the point estimates are not significantly different from 0.1, which indicates a fair degree of stability for this parameter. The only exception is provided by Regression II, where the point estimate of n happens to have the highest standard error.

It is noteworthy that Models I, III, and IV provide better fits than Model II measured in terms of r^2 and t-statistics. It will be recalled that while fixed and opportunity costs were set equal to zero in Model II, some measure of these costs was included in the other model specification. The results indicate that fixed and opportunity costs influence the decisions of boat owners whether they should participate in the herring fishery.

On *a priori* grounds, Model IV might appear to be a better specification than Model III. Although the statistical fit is somewhat better for Model IV, there is not sufficient evidence to prefer it at the expense of Model III. The point estimate of fixed costs per boat in Model III of NOK 193,000 is not unreasonable compared to the figures in Table 2. Also, Model IV indicates that an increase in the real price of mackerel, presumably causing an increase in the opportunity cost of herring fishermen, will lead to a decrease in participation in the herring fishery.

Wilen (1976) estimated a similar capital entry-exit equation for the North Pacific fur seal fishery. For the period with open access exploitation (1886–1900), a point estimate of n of 0.02 was obtained. This indicates considerably slower capital adjustment than in the herring fishery, presumably due to fewer alternative employment opportunities for sealers than for herring fishermen. The cutoff return per vessel was estimated to be \$4,800.00.

As noted above, there could be reason to expect a more rapid response in terms of entry due to positive profits than exit due to negative profits. To test for such an asymetric response, we shall follow a procedure suggested by Wolfram (1971). We specify the following asymetric response function:

$$K_{t+1} - K_t = n^+ P_t^r + n^- P_t^f$$

where

$$P_t^r = \sum_{t=1}^{T} \left(\frac{\Pi_t/p_t}{K_t} - \frac{\Pi_{t-1}/p_{t-1}}{K_{t-1}} \right) X_t^r$$

$$P_t^f = \sum_{t=1}^{T} \left(\frac{\Pi_t/p_t}{K_t} - \frac{\Pi_{t-1}/p_{t-1}}{K_{t-1}} \right) X_t^f$$

$$X_t^r = 1 \text{ iff } \frac{\Pi_t/p_t}{K_t} \geqslant \left(\frac{\Pi_{t-1}/p_{t-1}}{K_{t-1}} \right) \text{ and otherwise zero,}$$

$$X_t^f = 1 \text{ iff } \frac{\Pi_t/p_t}{K_t} < \left(\frac{\Pi_{t-1}/p_{t-1}}{K_{t-1}} \right) \text{ and otherwise zero.}$$

According to this model specification, there will be further entry to (exit from) the fishery only insofar as current period profits per boat exceed (are less than) the previous period's profits. n^+ and n^- measure change in fleet participation in response to rising and falling profits respectively.

Estimating the model* gave the following results:

Parameter	Point Estimate	t-statistic
n^+	0.0940	2.86
n^-	0.0855	3.30

Although the point estimate of n^+ is slightly higher than that of n^-, the difference is statistically insignificant. Accordingly, the empirical results do not support the hypothesis that entry in response to positive profits is more elastic than exit due to negative profits.

The boats in question are purse seiners that may participate in up to seven seasonal fisheries. If profits per boat are high in the North Sea herring fishery, entry will be rapid. Similarly, as the boats have alternative fishing opportunities, exit will be rapid in response to falling profits. Accordingly, the result that the rate of exit is not statistically different from the rate of entry is an indication of the availability of alternative fisheries.

So far, it is assumed that adjustments in capital depend on current period profits per unit of capital and possibly the return in the alternative fishery. In any one year, there exists a fleet of a given number of boats. However, new boats may also be built in response to the existence of positive profits in excess of the alternative return on capital. Since it takes time to construct new boats, this is an argument for including lagged values of average profits per boat as explanatory variables. The length of the time lag to be specified should correspond to the construction time for new boats. We have specified the following lagged versions of the estimating equations:

$$K_{t+1} - K_t = n\left(\frac{\Pi_t}{K_t}\right) + n_1\left(\frac{\Pi_{t-1}}{K_{t-1}}\right) + n_2\left(\frac{\Pi_{t-2}}{K_{t-2}}\right) \qquad \text{(LI)}$$

$$K_{t+1} - K_t = n\left(\frac{\Pi_t}{K_t}\right) + n_1\left(\frac{\Pi_{t-1}}{K_{t-1}}\right) + n_2\left(\frac{\Pi_{t-2}}{K_{t-2}}\right) + nf\left(\frac{1}{p_t}\right),$$

$$f_t = \bar{f}\ \forall\ t \qquad \text{(LII)}$$

$$K_{t+1} - K_t = n\left(\frac{\Pi_t}{K_t}\right) + n_1\left(\frac{\Pi_{t-1}}{K_{t-1}}\right) + n_2\left(\frac{\Pi_{t-2}}{K_{t-2}}\right) + n_3\left(\frac{P_{M,t}}{p_t}\right) \qquad \text{(LIV)}$$

Here, an adjustment lag of a maximum of two periods (years) has been specified, which appears quite reasonable compared to the time required for constructing and building new purse seiners. Parameters n_1 and n_2 are both expected to be positive. The lagged version of Model II has been excluded from further analysis, since the three other models performed better than this model. The results are given in Tables 4, 5, and 6.

* OLS estimation. $r^2 = 0.53$, $\bar{r}^2 = 0.49$, and DW = 1.82. Fixed and opportunity costs as per Table 2 were included.

Table 4
Estimation of Capital Dynamics Equation for the Period 1963–77, Model LI[a]

Regression	n	n_1	n_2	$n + n_1 + n_2$	r^2	$\bar{r}^2$	DW	Method[b]
LI.1	0.0883**	−0.0192	0.0238	0.0929	0.67	0.60	2.00	OLS, LAG = 1, 2
	(4.06)	(−0.76)	(1.08)					
LI.2	0.0796**	—	0.0153	0.0949	0.65	0.62	2.26	OLS, LAG = 2
	(4.39)		(0.83)					

[a] In this specification, fixed costs as given in Table 2 are included in the profit function.
[b] LAG indicates the order of the lagged variable.

Table 5
Estimation of Capital Dynamics Equation for the Period 1963–77, Model LIII

Regression	n	n_1	n_2	nf	Derived f NOK	$n + n_1 + n_2$	r^2	$\bar{r}^2$	DW	Method
LIII.1	0.1370**	−0.0259	0.0950**	−43,429.0**	317,000	0.2061	0.75	0.67	0.78[a]	OLS,LAG = 1,2
	(4.98)	(−0.90)	(2.67)	(−4.18)						
LIII.2	0.1243**	—	0.0847**	−44,114.0**	354,899	0.2090	0.73	0.67	0.99[a]	OLS,LAG = 2
	(5.29)		(2.54)	(−4.47)						

[a] Although the DW statistic is very low for this regression, it has not been corrected for first-order autocorrelation. Doing that does not affect point estimates very much, but is seen to blow up t statistics and r^2.

Table 6
Estimation of Capital Dynamics Equation for the Period 1963–77, Model LIV

Regression	n	n_1	n_2	n_3	$n + n_1 + n_2$	r^2	$\bar{r}^2$	DW	Method
LIV.1	0.1291**	−0.0204	0.0409*	−330.50*	0.1496	0.72	0.63	1.96	OLS, LAG = 1, 2
	(4.58)	(−0.68)	(1.44)	(−4.02)					
LIV.2	0.1195**	—	0.0327	−337.27**	0.1522	0.71	0.65	2.10	OLS, LAG = 2
	(5.03)		(1.31)	(−4.25)					

From the results in Tables 4–6, the following conclusions can be drawn:

1) The inclusion of lagged variables is seen to improve the explanatory power of Models III and IV, measured in terms of both adjusted r^2 and t-statistics, while there is less improvement for Model I. This indicates that the evidence with respect to lagged adjustment to changes in profitability conditions is inconclusive.

2) All point estimates of n_1 are of the wrong sign and insignificant. Excluding the variable profits per boat lagged once causes only insignificant changes in other parameter estimates and a slight improvement in adjusted r^2, which suggests the variable is redundant. Point estimates of n_2 are highly significant in Model III and in one case significant at the 90% level in Model IV. Accordingly, while a one year lag is clearly rejected, there is some evidence which suggests that if a time lag is to be considered, a two year lag should be specified. This corresponds to the time required for constructing and building new boats.

3) Point estimates of n are in general remarkably stable and not significantly different from 0.1, compare also the results of Table 3. The same is true for the combined effects of the variables profits per boat ($n + n_1 + n_2$). The exception is Model III with profits per boat lagged twice, where the combined effect is higher than in the other regression results.

4) The three models represent alternative hypotheses about the opportunity cost of capital, but the empirical results do not clearly validate any one hypothesis at the expense of the others. However, the empirical results indicate that the alternative cost of capital is affected by the profitability in the mackerel fishery, as represented by the relative price of mackerel.

5) The point estimates of the cutoff rate of return vary between NOK 317,000 and NOK 355,000 (Model III). Compared to the figures in Table 2, these are not unreasonable.

Conclusions and Recommendations

The present analysis started out with the hypothesis that fleet adjustment is proportional to profits in the fishery. However, it was acknowledged that a discrete time model might be more appropriate than continuous time models, in response to the fact that once boats are committed to one fishery, they are reluctant to regear for another fishery.

This basic adjustment hypothesis was to a large extent supported by the empirical results from estimating capital dynamics for the North Sea herring fishery. Various alternatives for the opportunity cost of capital were specified. In one model, it was related to the returns in the mackerel fishery, which might be considered an alternative to fishing herring. More elaborate models, which introduced lagged variables to reflect adjustment time to changes in profitability conditions such as the time required to build new boats, showed some improvements in the statistical fit.

The empirical analysis of the herring fishery was made difficult by a somewhat short time series, a condition that is likely to exist in several fisheries. The specification of alternative models did not cause a marked improvement in the empirical results. These indicate that fleet adjustment primarily depends on current period profits and that the opportunity cost may depend on returns in the alternative fishery. The results are likely to be of relevance for estimating capital dynamics in other fisheries.

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