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Efficiency Aspects of Fishery Management:
The Case of the North Sea

by
Chungsoo Kim[†]

October 1981

Institut für Weltwirtschaft an der Universität Kiel

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EFFICIENCY ASPECTS OF FISHERY MANAGEMENT:
THE CASE OF THE NORTH SEA

I. Introduction

1. Objective

In the case of fisheries, the lack of an efficient property rights structure (uniform, exclusive, and transferable property rights) is widely recognized as the prime impediment to higher profitability of the fishing industry and to the prevention of over-exploitation. This study uses an empirical model for measuring the economic efficiency implications of the competitive exploitation of a commonly shared fishery. While lack of data prevents the empirical application of theoretical state-of-the-art fishery models, the specification of the model used here does not prevent an analysis of the central efficiency question. Within a 'surplus-production' model of the North Sea fishery, economically optimal levels of fishing effort, cost, revenue, and rent are estimated. These are compared with activity levels that are considered optimal in the biological sense.

The paper begins with a review of the optimality conditions. Section II presents an empirical model, whose application to the multi-species North Sea fishery is discussed in Section III. Section IV presents empirical results.

2. Optimality Conditions

As a renewable resource, the stock of fish is dependent on the stock's rate of reproduction, the rate of natural mortality, and the intensity of fishing. Thus, the population dynamics of a fishery¹ can be represented by

$$\frac{dB}{dt} = g(B) - f(E, B) \quad (1)$$

where $g(B)$ is the net natural growth of the stock B (reproduction minus mortality) and $f(E, B)$ is the attrition of the stock due to fishing, which, in turn, depends on the stock size, B , and on the amount of resources used in fishery, as represented in the composite factor "fishing effort", E .

Optimality in resource use requires maximization of its present value. With perfect competition in product and factor markets, the present value of the resource is

$$\int_0^{\infty} [\bar{p} \cdot f(E, B) - w \cdot \bar{E}] \cdot e^{-\delta t} dt \quad (2)$$

where δ is the social rate of discount and w is the constant unit cost of fishing effort. Maximization of the present value subject to condition (1) yields the economically optimal level of fishing. This is equivalent to an optimal control problem where the Hamiltonian

$$H = [\bar{p} \cdot f(E, B) - w \cdot \bar{E}] \cdot e^{-\delta t} + \lambda [\bar{g}(B) - f(E, B)] \quad (3)$$

¹ For extensive discussions and a survey of fishery economics, see Clark (1976) and Peterson and Fisher (1977).

is maximized². λ is the marginal user cost of the resource in situ (uncaught fish), representing the amount by which the present value is changed if the stock size changes by one unit.

For a dynamic optimum, the following necessary conditions have to be satisfied:

$$H_E = (p \cdot f_E - w) \cdot e^{-\delta t} - \lambda f_E = 0 \quad (4)$$

$$\frac{d\lambda}{dt} = -H_B = -p \cdot f_B \cdot e^{-\delta t} - \lambda (g_B - f_B) \quad (5)$$

which imply

$$\lambda = e^{-\delta t} \cdot \left[\frac{-p \cdot f_B \cdot f_E - \delta (p \cdot f_E - w)}{f_E \cdot (f_B - g_B)} \right] \quad (6)$$

Marginal user cost falls as the social rate of discount rises.

Substitution of (6) into (4) yields the optimum condition³:

$$p = \frac{w}{f_E} + \frac{p \cdot f_B \cdot f_E - \delta (p \cdot f_E - w)}{f_E \cdot (f_B - g_B)} \quad (7)$$

For the exploitation of the fishery to be at the optimal level price has to be equal to the sum of marginal harvesting cost (w/f_E) and marginal user cost at any given movement of time.

² In the maximum principle problem E is the control variable, B is the state variable, and λ is the costate variable.

³ The optimum condition can alternatively be expressed as:

$$g_B = \delta - \frac{w \cdot f_B}{p \cdot f_E - w},$$

which implies that the fish stock should be maintained at the level of the maximum growth if both discount rate and harvesting cost are zero, and that it should be reduced from the level of the maximum growth if harvesting cost alone is assumed to be zero.

Empirical studies of fisheries face the problem that marginal user cost cannot be observed directly. In this study, it is assumed that the social rate of discount is zero, which in turn leads to an overestimate of marginal user cost. While this assumption, which renders the above model empirically applicable, may appear to be rather extreme, Hanneson (1974) provides empirical evidence that the fishing level in the absence of discounting will, in fact, not differ much from the optimal level when a discount rate of 10 % is used⁴. With future net benefits not being discounted at all, this assumption is equivalent to maximization of stationary rent. Under these stationary conditions, the optimum condition is

$$p = \frac{w}{f_E} + \frac{p \cdot f_B}{(f_B \cdot g_B)} \tag{8}$$

A comparison of (7) and (8) illustrates that the assumption of a zero social rate of discount leads to the most conservative approach to resource exploitation.

⁴ C. J. Hanneson (1974), pp

II. The Model

To arrive at an empirical specification of the population dynamics (1), it is conventionally assumed that, in the absence of fishing, the stock grows according to a logistic growth curve⁵:

$$g(B) = a \cdot B(B_m - B) \quad (9)$$

where B_m is the maximum stock size under prevailing environmental (space, food, etc.) conditions. As the stock approaches the environmental carrying capacity, the growth rate $a \cdot (B_m - B)$ declines linearly, reaching zero at B_m .

The general catch function of equation (1), $f(E, B)$, is now assumed to be multiplicative, where catch is proportional to the product of effort and stock size⁶:

$$f(E, B) = q \cdot E \cdot B \quad (10)$$

Combination of (9) and (10) leads to the empirical specification of population dynamics

$$\frac{dB}{dt} = a B(B_m - B) - q \cdot E \cdot B \quad (11)$$

⁵ The specification of the logistic growth function goes back to Schaefer (1954); for subsequent discussion and application, see Gordon (1954), Gulland (1961), Bell (1974), and Cadima (1978). The logistic growth function, together with the following catch function, forms what by Low (1975) has been called the 'surplus-production' model, illustrating the effect of fishing on fishing mortality. In contrast, the 'dynamic-pool' model of Beverton and Holt (1957) focuses on the basic parameters of population dynamics.

⁶ For discussions of the catch function of the mass-contact form, see Gordon (1954), Paloheime and Dickie (1964), Bell (1974), Hanneson (1974), and Cadima (1978).

The biological equilibrium condition

$$a \cdot B(B_m - B) = q \cdot E \cdot B \quad (12)$$

gives the steady-state relation ($\frac{dB}{dt} = 0$) between natural growth and fishing effort. From the stock-effort equilibrium (12), the steady-state relation between catch and effort can be obtained by expressing (12) in terms of B,

$$B = \frac{aB_m - qE}{a}$$

and substituting this into (10), yielding

$$q \cdot E \cdot B = q \cdot B_m E - \frac{q^2}{a} \cdot E^2 \quad (13)$$

According to (13), the steady-state catch is a parabolic function of fishing effort. The maximum steady-state catch level is called maximum sustainable yield (MSY). It is apparent that as an optimality criterion MSY only takes biological considerations into account. In contrast, economic optimality requires consideration of the (harvesting and user) cost of fishing. Maximization of the economic rent of the fishery in the stationary context chosen is equivalent to maximization of the Lagrangean

$$L = p \cdot q \cdot E \cdot B - w \cdot E + \lambda \left[\bar{a} \cdot B(B_m - B) - q \cdot E \cdot \bar{B} \right] \quad (14)$$

where λ , again, is marginal user cost. The necessary conditions for a stationary optimum are

$$L_E = p \cdot q \cdot B - w - \lambda \cdot q \cdot B = 0 \quad (15)$$

$$L_B = p \cdot q \cdot E + \lambda \left[\bar{a} B_m - 2aB - q \bar{E} \right] = 0 \quad (16)$$

$$L_\lambda = a \cdot B(B_m - B) - q \cdot E \cdot B = 0 \quad (17)$$

Solving (16) for marginal user cost

$$\lambda = \frac{p \cdot q \cdot E}{a B_m - 2 a B - q \cdot E} \quad (18)$$

and substituting (18) and (16) into (15) and then solving (15) for the value of the marginal product yields

$$p \cdot q \cdot \frac{a B_m - q \cdot E}{a} = w - \frac{p \cdot q \cdot E}{a B_m - 2 a \cdot \frac{a B_m - q \cdot E}{a}}$$

$$\cdot q \frac{a B_m - q \cdot E}{a} \quad (19)$$

In simplified form, this can be

$$p (\alpha_1 - \alpha_2 E) = w + p \alpha_2 E \quad (20)$$

where $\alpha_1 = q \cdot B_m$, $\alpha_2 = \frac{q^2}{a}$, or in functional notations,

$$\alpha_1 - \alpha_2 E = f_E, \quad \frac{\alpha_2 E}{\alpha_1 - \alpha_2 E} = \frac{f_B}{f_B - g_B};$$

The second term on the right-hand side of (20), $p\alpha_2 E$, is marginal user cost of fishing effort. The rent-maximizing condition

$$p = \frac{w}{\alpha_1 - \alpha_2 E} + \frac{p\alpha_2 E}{\alpha_1 - \alpha_2 E} \quad (21)$$

dictates that price must be equal to the sum of marginal harvesting and user cost. Integrating (20) with respect to E yields the maximum rent

$$\pi_{\max} = p(\alpha_1 E - \frac{1}{2}\alpha_2 E^2) - \frac{1}{2}p\alpha_2 E^2 - wE \quad (22)$$

where $p(\alpha_1 E - \alpha_2 E^2)$ is total revenue minus total user cost. For purposes of interpretation of the empirical results in Section IV, the profit-maximizing condition (21) (or (20)) can be rewritten as

$$p(\alpha_1 - 2\alpha_2 E) = w \quad (23)$$

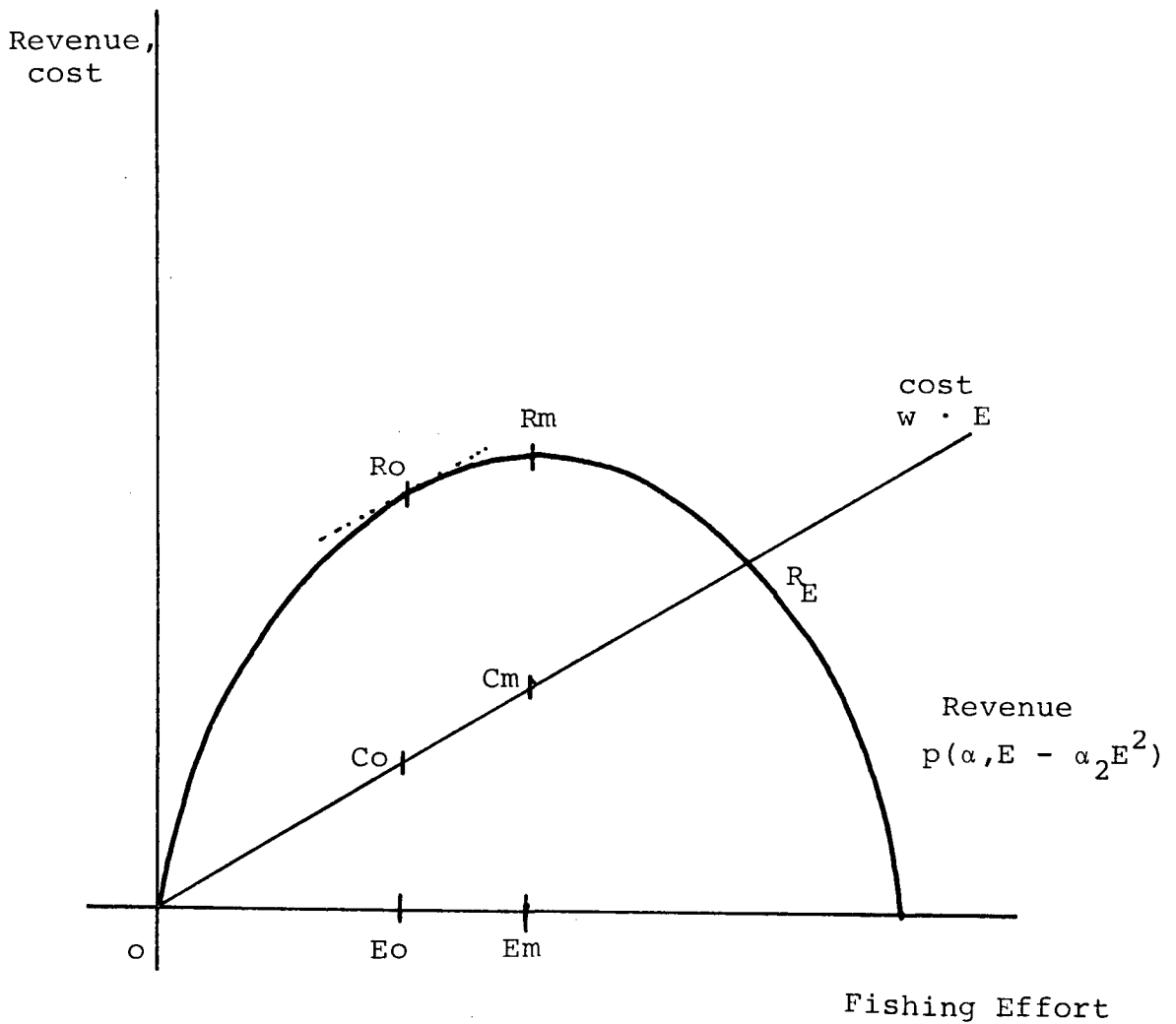
According to (23), in the stationary optimum fishing effort should be maintained at a level at which the unit cost of effort equals the value of the marginal product of effort net of marginal user cost of effort. The advantage of this reformulation is that the empirical specification adopted in this paper allows identification of the user cost term $p\alpha_2 E$.

Figure 1 shows the steady state ("sustainable") revenue-effort relationship. With the corresponding cost curve, wE , the optimal stationary effort level is E_0 , yielding revenue R_0 at a cost of C_0 . Maximum rent is $R_0 - C_0$.

Maximization of rent requires that both harvesting and user cost enter into the profit-maximizing calculus of individual fishermen. In general, identity of private and social maximizing behavior can only be achieved under an efficiency-oriented property rights regime⁷. This condition is violated under open access to fishing grounds. Since individual property rights over fish can, under open access, only be established by seizure, the value of the resource in situ (the uncaught stock) will not enter into the profit-maximizing calculus of individual fishermen. Thus, user cost will be disregarded by individual fishermen competing in the use of a commonly shared stock.

⁷The equilibrium characteristics of unregulated resource exploitation have been discussed extensively; cf. Gordon (1954), Clark (1976), Peterson and Fisher (1977).

Figure 1 - Biological and Economic Optima of a Commercial Fishery



Under open access conditions, each fisherman i attempts to maximize his own share of current industry profits:

$$\max_i p \cdot \frac{f(E, B)}{E} \cdot E_i - wE_i,$$

leading to the condition

$$p \cdot \frac{f(E, B)}{E} = w.$$

Potential future profits will not be taken into account, since under competitive open access conditions they are not privately appropriable in the current period. This individual maximizing behavior leads to an industry equilibrium where in each period

$$pf(E, B) - wE = 0.$$

Expressed in terms of the specific functional forms discussed above, the stationary state of the open access fishery is reached when

$$P(\alpha_1 E - \alpha_2 E^2) - wE = 0. \tag{24}$$

This corresponds to point R_E in figure 1, where the cost curve intersects the sustainable revenue curve. Under open access user cost is disregarded and the economic rent from fishing is dissipated by an excessive level of effort (and cost).

It is, of course, an empirical question whether or not the open access equilibrium deviates markedly from the social optimum. Abolishing the open access condition is only warranted if the potential economic rent exceeds the costs of

establishment and enforcement of an efficiency-oriented fishery management regime⁸.

⁸ Efficiency-oriented fishery management requires (1) establishment of jurisdiction (property rights) over the fishery and (2) imposition of a user fee to capture economic rent, if private property rights can - for political or other reasons - not be established over ocean areas. On the institutional characteristics of such a system, cf. Christy and Scott (1965), Christy (1972), Scott (1979), Pearse (1979), and Prewo (1980).

III. Application

Among major fisheries, the North Sea fishery offers a prime testing ground for the empirical model proposed in this paper. In the North Sea, overfishing has been apparent for many years to the extent that it is even feared to have led to the extinction of selected species⁹.

As a first step towards measuring the potential economic rent in the case of North Sea demersal species¹⁰, the locus of sustainable revenue (exclusive of user cost) - as shown in figure 1 by

$$p (\alpha_1 E - \alpha_2 E^2) \quad (25)$$

- is estimated. Construction of the cost curve WE allows identification of the open access equilibrium (24) and of the stationary social optimum (23). This, in turn, allows quantification of the maximum potential rent (23) and of user cost.

Due to the well-known paucity of economic data on fisheries, there have been few successful attempts at empirical applications of fishery models of the Schaefer type discussed here. The Schaefer model assumes that the fishery is restricted to a single fishing ground. This restriction is satisfactorily accommodated in the present study, since it chooses a relatively large fishing ground and it restricts itself to

⁹ For evidence on the state of biological exploitation of the North Sea fishery, cf. ICES (1976, 1978), Wilson and Anderson (1977), Saeterdal (1978), or the 'Review of State' series of FAO.

¹⁰ Demersal species are bottom-dwelling species such as cod, haddock, plaice. They are distinguished from pelagic species such as herring or tuna. The latter's migratory patterns are not confined to the North Sea.

demersal species whose migratory patterns are more narrowly confined than those of other (pelagic) species. In addition the Schaefer model assumes that the fishery is directed at a single species only, whereas, in reality, biological and technological conditions mandate a multi-species approach¹¹. To circumvent this problem, this study suggests an empirical scheme under which the various species in a multi-species fishery (such as the North Sea) are aggregated into a "composite" single species, thus retaining the empirical advantages of the single-species approach. (For details on data construction and sources, see the Appendix). The aggregation scheme offered here starts by weighing the catch of a species by its relative price to a numeraire species (here: cod)¹². Thus the total value-weighted catch in any fishing period is given by

$$CEW = \sum_{i=1}^n c_i p_i \quad (26)$$

where CEW is total (cod-equivalent) value-weighted catch, c_i is the volume weight of species i caught, and p_i is the relative price of species i .

In Schaefer-type models, fishing is envisioned as being carried out with a single composite factor of production, fishing effort. Following other studies, fishing effort is measured in terms of fishing hours of a "standard" fishing boat¹³. The fleet's total fishing effort expended on total catch CEW is then given by

¹¹ For this reason, cost data can also not be broken down by individual species in a multi-species fishery.

¹² For discussions of value-weighted catch in the management of multi-species fisheries, see Anderson (1975), Clark (1976); Huppert (1979) summarizes this discussion.

¹³ See the Appendix for definitions and underlying assumptions in constructing fishing effort data in terms of the efficiency unit of the standard fishing boat.

$$E = CEW / c_s / h_s \quad (27)$$

where c_s and h_s are catch level and fishing hours of the standard boat, respectively.

Finally this study is restricted to annual observations for the period from 1954 to 1973. During this period, unlike at present, quotas were not imposed and fishing took place in an open-access environment¹⁴. Table 1 summarizes the data on catch and effort for the sample period.

¹⁴ While quotas were not imposed during the sample period, technological restrictions (on fishing gear) have been. These technological restrictions, however, are widely considered as not having led to a sizeable impact on overfishing. Cf. references in note 9 above.

Table 1

North Sea Demersal Fisheries: Sample Data for 1954 - 1973

Year	Catch	Effort	CPUE
1954	.649	1.26	.517
55	.742	1.23	.605
56	.875	1.51	.581
57	.912	1.86	.490
58	.887	1.86	.477
59	1.085	2.52	.431
1960	.898	2.48	.363
61	.883	2.66	.332
62	1.232	3.72	.332
63	1.357	4.98	.272
64	1.359	4.53	.300
1965	1.449	4.43	.327
66	1.567	4.44	.353
67	1.718	4.89	.351
68	2.535	7.17	.353
69	2.403	6.34	.379
1970	2.580	7.67	.336
71	2.041	6.29	.325
72	2.101	7.46	.282
73	1.669	7.92	.211

Cod-equivalent-weights of catch have been estimated in million tons, based on Tables A1 and A2. Estimations of the catch per unit effort and the effort, whose units are CEW ton per hour and million CEW tons, are based on Table A3.

IV. Results

1. Sustainable Revenue

As a first test, it is assumed that the fishing power of boats changes in direct proportion to the changes in boat tonnage. Since the tonnage characteristics of the British fishing fleets (motor trawlers) have remained roughly constant over time, this assumption implies that the productivity of the standard fishing boat is assumed to have remained constant over the period under consideration. This assumption will be relaxed later in the paper (Section IV.3).

Due to biological factors - most notably: age composition and reproduction characteristics - current fishing influencing not only current but also future harvest potentials. However, this relationship is not known with accuracy. Lacking any prior knowledge of these intertemporal effects, three alternative regressions of the sustainable revenue-effort relationship (25) are offered here¹⁵. These regressions differ only by the lag structure imposed on the independent variables with the general regression equation being

$$CEW_t = \alpha_1 \bar{E}_{t-s} + \alpha_2 \bar{E}_{t-s} \tag{28}$$

where

$$\bar{E}_{t-s} = \frac{(E_t + \dots + r \bar{E}_{t-s})}{s + 1}$$

¹⁵ In other studies, e. g. Gulland (1961), Bell (1974) the catch-effort relationship of the quadratic functional form is reformulated for the regression function

$$\left(\frac{C}{E}\right) = a + bE.$$

As discussed by Roff and Fairbairn (1980), there are statistical problems with a specification in which the independent variable appears in the denominator of the dependent variable. However, the appealing simplicity of the 'surplus-production' fishery model is acknowledged even by its critics, cf. Schnute (1977) and Uhler (1980).

The three regressions differ according to s being alternatively set at 1, 2, and 3, implying a lag structure including 2, 3, and 4 annual observations on effort, respectively¹⁶.

The individual ordinary least squares regressions results are reported in Table 2. Since the Durbin-Watson statistics of the OLSQ regressions are rather low, indicating positive serial correlation, the regressions were also estimated using the Cochrane-Orcut (CORC) procedure; these results are also reported in Table 2. The estimated coefficient on E (a_1) carries the expected positive sign and is highly significant in all regressions. The coefficient on E^2 (a_2) is, as expected, negative in all regressions and is significant at least at the 5 % level; regression 2' (CORC) is an exception and has therefore been dropped from further discussion.

The regression results do not allow a decided judgment favoring one lag structure over the others¹⁷. As a consensus estimate, the simple average of the five results is

$$CEW = 521.7 E - 0.0319 E^2.$$

¹⁶ Depending on the length of the life cycle, alternative lag structures have been experimented with for individual species fisheries; for use of current effort, see Bell (1974); average effort levels of current and 2 or 3 past fishing periods are used by Gulland (1961) and F. A. O. (1978); 5 year averages are used by F. A. O. (1968).

¹⁷ The results show that the adjusted R^2 falls somewhat as longer lag structures are imposed on effort. However, the difference in R^2 is not sufficient evidence for discriminating among the equations.

Table 2

Revenue-Effort Regressions of North Sea Demersal Fisheries:

$$C = a_1E + a_2E^2$$

Equations	Estimated Coefficient		\bar{R}^2	ρ	D-W
	a_1	a_2			
<u>OLSQ</u>					
1 (average effort of 2 years)	479.9 (8.85)	-.0250 (2.85)	.75		.87
2 (average effort of 3 years)	501.5 (8.56)	-.0275 (2.82)	.72		.82
3 (average effort of 4 years)	544.3 (8.74)	-.0341 (3.23)	.69		.90
<u>CORC</u>					
4 (average effort of 2 years)	509.3 (4.98)	-.0317 (2.07)	.81	.603	1.90
5 (average effort of 3 years)	451.1 (3.94)	-.0212 (1.19)	.80	.615	1.72
6 (average effort of 4 years)	573.5 (4.77)	-.0410 (2.14)	.76	.579	1.80
Average of estimates (eqs. 1,2,3,4,6)	521.7	-.0319			

The regressions are based on the data in Table 1; the numbers in parantheses are t-statistics; ρ is the final value of rho in the iteration of the Cochrane-Orcutt estimation procedure.

The regression results show that the sustainable revenue-effort relationship is of the postulated inverted U-shape. Total revenue (in terms of value-weighted catch) reaches a maximum of 2.2 million CEW tons at an effort level of 8.2 million fishing hours: This is the level corresponding to the biological criterion of maximum sustainable yield (MSY). The force of declining marginal returns can be illustrated as follows: At an effort level of 2.5 million fishing hours (reached around 1960) a 1000 hour increase in effort raises revenue by 362 CEW tons. On the other hand, at an effort level of 7.5 million hours (reached at 1972), the same effort increase would lead to a marginal revenue of only 43 CEW tons.

The average (and marginal) harvesting cost (of fishing effort) has been calculated at 211 CEW tons per 1000 fishing hours¹⁸. This can be contrasted with estimates for the variable marginal user cost ($p\alpha_2 E$) that can be derived from the regression results. At the relatively low effort level of 2.5 million hours, marginal user cost is 80 CEW tons (per 1000 fishing hours), i. e., less than 40 % of marginal harvesting cost. On the other hand, at the relatively high effort level of 7.5 million tons, marginal user cost (at 239 CEW tons) exceeds marginal harvesting cost (211 CEW tons). In the years after 1968, marginal user cost in general exceeded marginal harvesting cost, which already provides some indication of the inefficiency implied by the open access regime.

¹⁸ Derivation of alternative estimates of harvesting cost, see the Appendix.

2. Optimal Exploitation

The revenue and cost curves estimated for the demersal species fisheries of the North Sea can be used for a comparison of the implications of biological and economic optimality criteria.

a) Economic optimum:

In the stationary state and in the terminology used here, the economic optimum is reached at that level of fishing where marginal revenue net of user cost (marginal sustainable revenue) equals marginal harvesting costs. For each of the five revenue - effort relationships, estimates of revenue, cost, effort and profit at the economic optimum have been calculated. The detailed results are reported in the Appendix, Table A4. The averages of these estimates are shown in the first column of Table 3¹⁹. The optimal fishing effort is reached at 4.9 million hours; the corresponding revenue amounts to 1.8 million CEW tons. At a harvesting cost of 1.04 million CEW tons, this implies sustainable economic rent of .76 million CEW tons, or 73 % of harvesting cost²⁰. At this level, the marginal user cost is 153 CEW tons per 1000 hours.

¹⁹ The five individual revenue estimates all fall into a narrow band of about 5 % around the average reported in Table 3. The individual effort estimates fall into a 10 % band around the average reported here.

²⁰ For comparison, the high-cost assumption implies an optimal revenue of 1.5 million CEW tons, 3.7 million hours of effort, harvesting cost of 1.06 million CEW tons, sustainable economic rent of .44 million CEW tons (or 41 % of harvesting cost), and marginal user cost of 118 CEW tons per 1000 fishing hours.

Table 3

Summary Estimates of Economic and Biological Optima

	Economic Optimum	Biological Optimum (MSY)
Revenue	1.80	2.16
Harvesting Cost	1.04	1.76
Effort	4.94	8.34
Rent	.76	.40
Rent as % of Cost	73	23

Revenue, cost, and rent are measured in million CEW tons, while fishing effort is measured in million fishing hours. The low cost assumption is used in this estimation. For details of estimates under both the low and high cost assumptions, see Tables A4 and A5.

These estimates allow an examination of the history of the North Sea demersal fishery in the light of efficiency. According to Table 1, the North Sea fishery has, upto the mid-sixties, grown rapidly both in terms of value-weighted catch (revenue) and fishing effort. Upto 1967, catch and effort have grown at average annual rates of 7.8 % and 11 %, respectively. Increasing profits were secured during that period of apparent development. In contrast, profits have been declining ever since 1968²¹. Fishing effort jumps from 1967 to 1968 by nearly 50 %. This excessive effort level has subsequently never been cut back to the optimal level, thus leading to continued, aggravated overfishing. Declining profits have been the expected result of persistent overfishing, a tendency characteristic of the open-access regime. In this period from 1968 to 1973 cost exceeded the optimal level by 46 % on average, while revenue exceeded the optimal level by only 26 %. From 1968 to 1973, the cumulative economic rent that has been wasted amounted to 370 thousand CEW tons²².

b) Biological optimum (MSY)

Biological optimality disregards costs. The criterion is maximum sustainable yield, reached when marginal revenue is zero. The second column of Table 3 gives the effort, revenue, cost and profit estimates corresponding to this optimality criterion. Accordingly, maximum sustainable yield (revenue) is reached at 2.16 million CEW tons with

²¹ This observation is, again, based on the low-cost assumption. The high cost assumption places the turning point at around 1963.

²² This figure is obtained in spite of the exceptionally good harvests of 1968 - 1970.

a fishing effort of 8.3 million hours. At a harvesting cost of 1.76 million CEW tons, economic profit is 0.4 million CEW tons, or 23 % of cost²³. Except for a few years, the North Sea demersal fishery has been carried out at levels below MSY, implying that the stocks have not been overfished according to this biological criterion²⁴.

The divergence between economic optimum and biological optimum (as defined by MSY) is striking. While MSY revenue exceeds the economically optimal level by 20 %, harvesting cost at MSY is 69 % above the economically optimal level. As a consequence, the rent at MSY is roughly only half of the optimal economic rent. This appears to disqualify MSY as an appropriate guide for fishery management.

3. Technological Advance

So far in this paper, the assumption that tonnage represents fishing power has implied the absence of technological change. This assumption will now be relaxed. While measures of technological change in the North Sea fishery are not available, the sensitivity of the results with respect to alternative assumptions of technological change can be tested. Three such sensitivity tests are provided here; in these three experiments, the annual rate of technological advance is, alternatively, set at 2.5 %, 5 %, and 10 %.

²³ At the alternative high-cost assumption, fishing at MSY would entail a loss of 9 % of cost. See the Appendix (Table A5).

²⁴ Seemingly, this is not true for the years 1968, 1969, 1970, when catch exceeded the MSY level. However, these years were biologically abnormal years, as is shown by the fact that effort levels were below MSY levels, while catch exceeded MSY. In 1968, the sudden increase of catch resulted from the exceptionally good harvest of a single species, Norway pout, and the good harvests of 1969 and 1970 can be attributed to haddock. Cf. Table A2 in Appendix and ICES (1975).

Under a constant rate of technological change, the efficiency adjusted catch per unit effort (of the standard fishing boat) in period t becomes

$$CPUE_t^+ = CPUE_t / (1 + \gamma)^t.$$

According to (27), the fishing effort, expressed in constant units of efficiency, becomes

$$E_t^+ = E_t \cdot (1 + \gamma)^t.$$

With averages of current and past values for E_t^+ as the new independent variable, the sustainable revenue-effort regressions can be rerun. The regression results are reported in the Appendix (Tables A6 through A8). In analogy to Table 3, Table 4 presents results on revenue, cost, effort, and rent for both the economic and biological optima and the technological advance assumptions.

Technological change does not qualitatively alter the conclusions reached in the case of economic optimization. 1968 remains the turning point of the fishery and the start of substantial economic overfishing. Quantitatively, the optimal economic rent increases from the previous value of .76 million CEW tons - at zero technological change - to, alternatively, 1.01 ($\alpha = 2.5\%$), 1.24 ($\alpha = 5\%$), and 1.61 ($\alpha = 10\%$). Thus, even at the most modest rate of technological advance (2.5%), rent exceeds harvesting cost.

With technological change, biological overfishing becomes more evident. While under the assumption of no technological advance, the criterion of MSY has not been violated²⁵ with technological

²⁵ As discussed above, the apparent violation of MSY in the years 1968 - 1970 can be attributed to abnormalities rather than to biological overfishing.

Table 4

Summary Estimates of Economic and Biological Optima under Alternative Assumptions
of Technological Advance

	Economic Optimum			Biological Optimum (MXA)		
	Assumption on γ			Assumption on γ		
	2.5%	5 %	10 %	2.5 %	5 %	10 %
Revenue	1.90	2.06	2.35	2.10	2.19	2.44
Harvesting Cost	.89	.82	.74	1.29	1.08	.91
Effort	6.80	9.98	23.36	9.83	13.26	28.75
Rent	1.01	1.24	1.61	.81	1.11	1.53
Rent as % of Cost	113	153	218	63	103	168

Units are the same as in Table 3. Estimates are based on the low cost assumption. Corresponding estimates based on the high cost assumption are reported in the Appendix (Table A9).

advance the years 1973 ($\alpha = 25 \%$) and 1971 ($\alpha = 5$ or 10%) are identified as the turning points at which the fishery moves to biological overfishing.

V. Summary and Conclusions

The central focus of this study has been on efficiency aspects of fishing. Like other empirical fishery studies, this study also has faced the obstacle posed by the lack of adequate data. The hurdle is insurmountable, if the goal is an empirical application of the dynamic models that are the state of the art in fishery theory. In the face of these difficulties, this study has resorted to a static framework. While this precludes the analysis of many interesting dynamic features, it offers a stylized picture of the fishery, in which the central efficiency questions are highlighted.

The major conclusions of the study, as applied to North Sea demersal fisheries in the period of 1954 to 1973 are: First, economic overfishing has become increasingly severe. While the North Sea fishery, if managed properly, entails economic rent of a substantial magnitude, most of that has been dissipated under open access. The urgency of installing a restrictive access regime is undisputed by the empirical evidence. Second, static biological optimality criteria such as MSY are entirely inadequate from the economic viewpoint. The considerable divergence between the biological and the economic optimum does not vindicate the casual assertion that, in the lack of better guides of fishery management, MSY retains practical usefulness. Without question, some of the empirical assumptions underlying this study are open to attack. One of the major assumptions - the absence of technological change - has been examined in detail. The results show that the qualitative conclusions remain robust to this experiment.

Appendix

Data Sources

Catch: The value-weights for the construction of composite catch figures of the North Sea multi-species demersal fishery are derived (i) from absolute catch data (weight) for individual species as reported in International Council for the Exploration of the Sea (ICES), Bulletin Statistique, various annual issues, and (ii) on the basis of relative catch prices of British takings as reported by the U. K. Ministry of Agriculture, Fisheries and Food, Sea Fisheries Statistical Tables, various issues. The data on relative prices are reported in Table A1, those on absolute catch weights in Table A2.

Fishing Effort: This study follows the common practice of relying on a composite factor of production, fishing effort. Fishing effort is measured by fishing hours of the "standard" boat, British motor trawlers, as reported in ICES, Bulletin Statistique, various issues. Catch per unit of fishing effort (CPUE) is then obtained by dividing the value-weighted catch by fishing hours of the standard boat.

Unit Cost of Fishing Effort: Direct cost data on the multi-species fishery of the North Sea are not available. To obtain proxies for the unobserved cost data, this study invokes the open access equilibrium condition that, in the long run, revenue must be at least as high as total harvesting cost. Thus, the observed catch per unit of effort (CPUE) should be at least as high as the unobserved unit cost of fishing effort; and, consequently, following Hanneson (1974), unit cost

can be measured by the lowest historical level of CPUE. For the North Sea fisheries considered here, 1973 shows the lowest CPUE level. For the low-cost calculation reported in the paper, the 1973 figure is used. For the high-cost calculation the minimum of the four-year averages of CPUE over the observation period (1954 - 1973) is used. This turns out to be the average of the years 1970 - 1973. This alternative cost figure is offered on the presumption that the low 1973 CPUE figure may reflect short-run disequilibrium phenomena.

Table A1

Changes in Relative Fish Prices in Comparison with Cod Price: 1954 - 1973 - British Takings

Year	Haddock	Plaice	Saithe	Whiting	Others
1954	1.32	2.47	0.75	0.89	1.71
1955	1.28	2.55	0.70	0.78	1.78
56	1.28	2.75	0.75	0.83	1.83
57	1.15	2.23	0.65	0.68	1.54
58	1.20	2.17	0.68	0.70	1.54
59	1.28	2.13	0.65	0.76	1.59
1960	1.13	2.06	0.61	0.76	1.47
61	1.15	2.05	0.70	0.72	1.54
62	1.23	2.21	0.74	0.75	1.78
63	1.29	1.81	0.58	0.61	1.55
64	1.15	1.74	0.47	0.55	1.55
1965	1.11	1.87	0.47	0.47	1.68
66	1.13	1.97	0.48	0.57	1.66
67	1.31	1.79	0.50	0.68	1.69
68	1.28	2.00	0.52	0.77	1.98
69	1.30	1.82	0.47	0.77	2.06
1970	1.19	1.53	0.45	0.61	1.70
71	1.23	1.23	0.45	0.53	1.17
72	1.20	1.20	0.43	0.61	1.17
73	1.11	1.11	0.39	0.51	1.02

Source: "Sea Fisheries Statistical Tables", Ministry of Agriculture, Fisheries and Food, U. K.

Table A2

Demersal Specie Fisheries from the North Sea: Unit = 1 ton

Year	Cod	Haddock	Plaice	Saithe	Whiting	Other Demersal	Total
1954	80.571	70.135	66.965	33.300	64.815	133.347	449.133
1955	83.448	87.656	63.315	40.892	72.436	168.828	516.575
56	80.267	93.917	63.881	46.598	74.943	219.976	579.582
57	94.981	105.304	69.272	51.850	84.314	264.370	670.091
58	103.733	96.191	72.429	47.772	77.484	283.065	680.674
59	109.467	79.670	78.324	46.655	80.491	387.001	781.608
1960	104.399	66.424	86.289	28.959	53.123	328.793	667.987
61	105.811	67.238	85.783	31.010	83.289	287.590	660.227
62	89.558	52.419	87.419	22.276	68.967	459.008	779.647
63	105.921	59.398	107.062	27.571	98.653	583.420	982.025
64	121.550	198.706	110.361	55.102	99.528	474.947	1.052.194
1965	179.469	221.700	96.927	68.907	106.694	452.071	1.125.768
66	219.702	268.958	100.130	86.927	155.153	431.402	1.262.272
67	249.803	167.408	100.646	72.504	91.245	574.258	1.255.864
68	285.314	139.469	108.838	97.397	144.920	854.301	1.630.239
69	199.035	639.175	121.652	105.980	199.029	460.348	1.725.219
1970	224.742	671.831	130.344	169.507	181.506	688.223	2.066.153
71	320.031	257.915	113.921	206.274	112.239	949.934	1.960.314
72	346.311	213.247	123.150	198.621	108.774	1.024.869	2.014.964
73	235.502	195.779	130.214	182.356	142.935	909.857	1.796.643

Source: "Bulletin Statistique", ICES

Table A3 - England & Wales Fishing Efforts and Catches with (Bottom) Motor Trawlers

unit: t

Year	Effort		Catch						Total Weight	Total Cod-valued Weight
	Fishing Hour	Average Gross Tonnage	C o d	Haddock	Plaice	Saithe	Whiting	Others		
1954	8524	.	178	105	.	926	7	1984	3200	4410
1955	13959	.	480	350	4	2536	8	3215	6593	8842
1956	10949	357	330	330	4	2509	13	2022	5208	6356
1957	13220	359	473	544	9	2550	36	2390	6002	6481
1958	19076	.	746	1103	21	3422	76	2987	8355	9095
1959	32929	.	1488	1477	23	4859	49	4752	12648	14179
1960	32192	.	1106	1032	18	4003	19	4698	10876	11672
1961	40699	.	1405	729	20	4029	17	5455	11655	13517
1962	40301	353	1713	1179	46	3303	51	4284	10572	13368
1963	40578	324	1538	1093	255	3759	81	3490	10216	11049
1964	44774	330	2551	1633	399	3990	37	4130	12740	13420
1965	40969	339	1936	1484	426	5287	51	3871	13055	13392
1966	50892	341	2452	4131	674	6077	154	3912	17400	17946
1967	45237	334	2741	3213	924	5001	100	2790	14769	15888
1968	68379	321	6287	3056	2427	3603	66	3633	19072	24170
1969	46257	343	4358	2365	1202	3644	78	2985	14623	17542
1970	34791	308	2489	2385	1280	2428	55	1935	10572	11701
1971	73431	291	7018	5944	3827	2873	88	2952	22702	23830
1972	107271	342	9709	6508	5155	3265	170	4276	29083	30215
1973	88365	347	5004	2811	5887	2748	116	2787	19353	18632

Source: 'Bulletin Statistique', ICES

Table A4 - Economic Optimum of the North Sea Demersal Fishery

I. Low Cost Assumption

	Regression Equation				
	1	2	3	4	6
Revenue	1.86	1.88	1.85	1.69	1.73
Harvesting Cost	1.13	1.11	1.03	.99	.93
Effort	5.4	5.3	4.9	4.7	4.4
Rent	.73	.77	.82	.70	.80
Rent as % of Cost	64	69	79	71	86

II. High Cost Assumption

Revenue	1.49	1.54	1.57	1.40	1.51
Harvesting Cost	1.11	1.12	1.08	1.01	1.00
Effort	3.9	3.9	3.8	3.6	3.5
Rent	.38	.42	.49	.39	.39
Rent as % of Cost	34	38	45	39	50

Equation numbers pertain to those in Table 2. Units are the same as in Table 3.

Table A5 - Biological Optimum (MSY) of the North Sea Demersal Fishery

I. Low Cost Assumption

	Regression Equation				
	1	2	3	4	6
Revenue	2.30	2.29	2.17	2.05	2.01
Harvesting Cost	2.02	1.92	1.68	1.69	1.48
Effort	9.6	9.1	8.0	8.0	7.0
Rent	.28	.37	.49	.36	.53
Rent as % of Cost	14	19	29	21	36

II. High Cost Assumption

Revenue	2.30	2.29	2.17	2.05	2.01
Harvesting Cost	2.75	2.61	2.28	2.30	2.00
Effort	9.6	9.1	8.0	8.0	7.0
Rent	-.45	-.32	-.11	-.25	.01
Rent as % of Cost	-16	-12	-5	-11	0

Table A6

Catch-Effort Regressions: 2.5 % Technological Advance

$$C = aE + bE^2$$

Estimated Coefficient

Equation	a	b		\bar{R}^2	ρ	D-W
<u>OLSQ</u>						
1	404.5 (11.46)	-.1923E-1 (5.21)		.75		.79
2	423,8 (11.03)	-.2106E-1 (5.05)		.72		.85
3	458.3 (11.79)	-.2417E-1 (5.65)		.73		.92
<u>CORC</u>						
4	418.3 (6.75)	-.2136E-1 (3.62)		.83	.608	2.00
5	404.8 (6.21)	-.1966E-1 (2.96)		.80	.552	1.90
6	464.5 (7.14)	-.2610E-1 (3.85)		.79	.533	1.91

Specifications are the same as Table 2.

Table A7

Catch-Effort Regression: 5 % Technological Advance

$$C = aE + bE^2$$

Equation	a	b	\bar{R}^2	ρ	D-W
<u>OLSQ</u>					
1	314.3 (13.46)	-.1122E-1 (7.20)	.75		.68
2	332.4 (13.00)	-.1252E-1 (6.98)	.72		.82
3	352.7 (14.33)	-.1401E-1 (7.87)	.75		.89
<u>CORC</u>					
4	315.0 (8.48)	-.1143E-1 (5.18)	.85	.6178	2.20
5	321.5 (8.23)	-.1194E-1 (4.68)	.82	.5308	2.15
6	353.5 (9.68)	-.1425E-1 (5.79)	.82	.4970	2.09

Table A8

Catch-Effort Regression: 10 % Technological Advance

$$C = aE + bE^2$$

Equation	a	b		\bar{R}^2	ρ	D-W
<u>OLSQ</u>						
1	163.2 (13.24)	-.2714E-2 (8.27)		.62		.43
2	178.3 (13.33)	-.3224E-2 (8.40)		.62		.53
3	189.1 (14.33)	-.3601E-2 (9.08)		.65		.58
<u>CORC</u>						
4	147.4 (8.06)	-.2286E-2 (5.93)		.86	.756	2.60
5	165.2 (8.54)	-.2841E-2 (5.89)		.84	.663	2.66
6	179.2 (9.90)	-.3296E-2 (6.93)		.84	.618	2.43

Table A9 - Fisheries with Technological Advance under High Cost Assumption

	Economic Optimum			Biological Optimum		
	2.5 %	5 %	10 %	2.5 %	5 %	10 %
Revenue	1.70	1.91	2.21	2.10	2.19	2.44
Harvesting Cost	1.03	1.01	1.02	1.81	1.58	1.47
Effort	5.57	8.48	19.98	9.82	13.25	28.75
Rent	.67	.90	1.19	.29	.61	.97
Rent as % of Cost	65	89	117	16	39	.66

Units are the same as in Table 3. Estimates are based in the high cost assumption.

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