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The Economic Structure of Harvesting for Three Vessel Types in the Norwegian Spring-Spawning Herring Fishery

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Abstract *Norwegian spring-spawning herring* (Clupea harengus) *is the largest fish stock in the North Atlantic and is harvested by many nations. The introduction of new technology in the 1960s resulted in a substantial increase in the efficiency of the fishing fleet. As a consequence, the stock was fished almost to extinction by the end of the 1960s. In the 1990s, the stock showed healthy growth and Total Allowable Catch (TAC) quotas have increased. This paper adds to the understanding of the harvesting process by providing measurements of the economic structure of the harvesting technology. For this fishery, Norway receives the largest share of the internationally determined TAC quota, and thus, the focus will be to investigate the harvesting process for three vessel types in the Norwegian fishing fleet: purse seiners, trawlers, and coastal vessels. Vessel-level cost and revenue data are available annually for these vessel types for the three-year period 1994–96. Estimates of input elasticities, economies of scale, and cost elasticities for a two-output cost function are reported.*

Key words Cost structure, harvest technology, Norwegian spring-spawning herring.

Introduction

The Norwegian spring-spawning herring (*Clupea harengus*) is the largest fish stock in the North Atlantic and an important source of revenue for many coastal states. Norway is the largest harvester, followed by Iceland and Russia. The Faroe Islands and the European Union are also significant agents in the fishery, but to a lesser degree. Throughout the 1950s, the stock was abundant and healthy. The introduction of new technology, in particular the powerblock, and modern fish-finding equipment, such as sonar, in the 1960s caused a tremendous increase in harvesting efficiency for purse seine vessels. As a result, catch levels increased, stock size decreased, and the stock was fished near extinction by the end of the 1960s.

After the collapse, it took about 20 years for the stock to recover to the Minimum Biological Acceptable Level (MBAL) and only in the second half of the 1990s,

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did stock size reached levels that allowed for increases in TAC quotas. Management of spring-spawning herring is complicated by the international migratory pattern of the species (Munro 1998). The migratory range extends from Norwegian coastal waters, through the Exclusive Economic Zones (EEZs) of the European Union, The Faroe Islands, and Iceland and through international waters called the "Ocean Loop" on their way to the summer feeding area near Jan Mayen Island. While the stock is in an EEZ, the authority for fisheries management lies with the individual country. On the high seas, the stock is, in principle, open for harvesting by many fishing nations. Efficient management of the fishery requires cooperation among the fishing nations involved and knowledge of both the biology of the fish and the economic structure of the harvesting process.

The purpose of this paper is to add to the understanding of the harvesting process by providing measurements of the economic structure of harvesting technology for three different vessel types that fish spring-spawning herring. Our focus will be to investigate the harvesting process for three vessel types in the Norwegian fishing fleet; *i.e.*, purse seiners, trawlers, and coastal vessels. A multi-output cost function is used to characterize the harvesting process. A cost function specification is based on the assumption that vessels take output as given or fixed, and the objective is to minimize the cost of harvesting the output level. The fisheries that we are modelling are regulated by quota restrictions or TAC levels, and a cost minimization assumption is consistent with such regulations.[1]

Norwegian Spring-Spawning Herring

In the 1950s and the 1960s, Norwegian spring-spawning herring was a major commercial species harvested by vessels from Norway, Iceland, the Faroe Islands, the former Soviet Union, and several European nations. During this period, the fishable component of the herring stock is believed to have measured about 10 million metric tons (MT). However, at this time, the stock was subjected to heavy exploitation by several European nations; especially Norway, Iceland, and the former Soviet Union, which were employing new and substantially more effective fishing technology. The annual harvest peaked at 2 million MT in 1966. By this time, however, the stock was in serious decline, and a complete stock collapse occurred by the end of the decade.

Prior to stock depletion, the species was a migratory stock moving through several coastal states and the high seas. The migratory pattern and number of components to the stock changed between 1950 and 1970. In the 1950s and early 1960s, adults would spawn off the south-central coast of western Norway (near Møre) from February through March. The adults would migrate west and southwest through international waters toward Iceland (April and May), spending the summer (June through August) in an area north of Iceland. In September, the adults would migrate south to a wintering area east of Iceland before returning to western Norway to spawn. Juveniles, including the recently spawned or "zero cohort," would migrate north, but remain in Norwegian waters until sexually mature, around age four or five, when they would join the adult migratory pattern.

In the mid-1960s, a second, more northern stock component appeared. This component would spawn south of the Lofoten Islands (north of Møre) with adults

[1] The dual cost function has a long history in applied econometrics. See Hall (1973); Binswanger (1974); Caves, Christensen, and Swanson (1981); Morrison (1985); Lipton and Strand (1992); and Weninger (1998) for applied examples of this modelling approach.

migrating northwest into the north Norwegian Sea, then northeast into the Barents Sea, and finally south to wintering grounds west of the Lofoten Islands before moving south to spawn. By 1966, the northern component was the larger of the two. Because of overfishing and poor recruitment, the spawning biomass of both components fell precipitously in 1968 and 1969. In its depleted state, the adult population ceased migration, and both adults and juveniles remained in Norwegian waters year-round.

It is worth emphasizing that spring-spawning herring is a straddling fish species only when the stock is in a healthy, abundant state. When the stock is depleted, it remains solely in Norwegian waters and under Norwegian fisheries jurisdiction. Moreover, as is the case with many clupeids, good year classes are recruited only at irregular intervals, and the stock is thus dependent on a few strong year classes (Bjørndal *et al.* 1998).

Recruitment remained weak throughout the 1970s, and it was not until the strong year class of 1983 joined the adult population in 1986 that the stock biomass began to recover. The main component of the stock has reestablished itself on the spawning grounds off Møre. Now, after spawning, the adult herring begin a westerly migration passing through the EEZs of the European Union, Faroe Islands, and Iceland and through international waters called the "Ocean Loop" on their way to the summer feeding area near Jan Mayen Island. In the 1990s, the herring followed the southern edge of the cold East Iceland stream, north and northeasterly, to winter in the fjords of northern Norway (Bjørndal *et al.* 1998).

Harvest quotas have increased considerably in the 1990s, from a total of 78,000 tons in 1992 to almost 1,500,000 tons in 1997. Norway receives about 60% of this allocation. In Norway, three vessel types participate in the herring fishery: purse seiners, coastal vessels, and trawlers. The Norwegian quota is allocated among these vessel groups. Table 1 shows the distribution of the total quota among the vessel groups. In 1996, coastal vessels were assigned 33% of the total quota, while purse seiners were granted 58%. The rest of the total quota for this year (9%) was allocated to trawlers. Quota levels for purse seiners and trawlers have increased in the period, while the share of the coastal vessels has been reduced. However, in tons, the quotas have increased for all groups in the period.[2]

The coastal vessels and the trawlers are assigned a maximum quota for each vessel group, while each purse seine vessel is assigned a vessel quota.[3] A vessel quota is reliable in the period and guaranteed by the authorities, while a maximum quota is not. This difference is due to the fact that purse seiners are licensed vessels, while the trawlers have permission to participate, and the coastal vessels have free access to the fisheries for Norwegian spring-spawning herring.[4]

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[2] Currently, a major portion of the landings, particularly for purse seiners, is used for human consumption. This contrasts sharply with the 1960s, when landings were used primarily for reduction purposes.

[3] See Asche, Bjørndal, and Gordon (1998), for a discussion of Norwegian fisheries regulations.

[4] For coastal vessels, the group quota is allocated among the 400 participating coastal vessels on the basis of a unity quota, which was set to 110 tonnes in 1997. The number of unity quotas each vessel is assigned depends on the length of the vessel. The smallest vessels (7 metres or less) were assigned one unity quota as a maximum quota, and the largest vessels (26 metres or more) were assigned 21 unity quotas as a maximum quota. For the 70 trawlers participating in the fishery, each was assigned a base quota dependent on the gross tonnage of the vessel and calculated by means of a given key. The maximum quota is set by multiplying the base quota by a factor, which is set by dividing the group quota by the sum of the base quotas. About 100 licensed purse seine vessels participate in the fishery, and each is assigned a base quota dependent on the licensed capacity of the vessel and calculated by means of a given distribution key. The vessel quota is set by multiplying the base quota by a factor. The factor is set by dividing the group quota by the sum of the base quotas.

Table 1
Norwegian Quota Distribution by Vessel Type, Tons

Year	Purse Seine	Trawler	Coastal Vessel	Total
1994	196,050 (50%)	24,850 (6%)	174,100 (44%)	395,000
1995	304,500 (55%)	45,500 (8%)	200,000 (37%)	550,000
1996	403,700 (58%)	62,550 (9%)	228,750 (33%)	695,000

Source: Norges Sildesalgslag 1996.
Note: percentage distribution in parentheses.

The Cost of Harvesting

The data available for analysis are obtained from the Norwegian Directorate of Fishery. They include information on catches, revenues, and costs for vessels that are 13 meters and larger for the three year period 1994–96**.** Table 2 shows the number of vessels for each vessel group for each year that data was available in the data set. The total sample of observations for purse seiners is 112, for trawlers 103, and for coastal vessels 158. For each vessel, data are available on the value (Norwegian kroner) and quantity (tons) of harvest of spring-spawning herring, North Sea herring, mackerel, and other species. Expenditure data are available on fuel, product fees, bait, social costs, insurance, maintenance (vessel and gear), miscellaneous, labor, and depreciation (based on historical cost). Finally, the vessel itself is measured by replacement value; that is, length, tonnage units, gross registered tons, and engine horsepower. All data are annual, boat-level data.

Because catch levels are set by quota, a cost function approach is used in measuring the economic structure of harvesting (Diewert 1974). Thus, the behavioral hypothesis imposed on the modelling process is that the fishing vessel attempts to minimize the cost of harvesting the set quota level subject to vessel type.

The input expenditure data are used to define two price indices; one measuring the cost of purchasing fuel and one aggregate index measuring the cost of maintaining the vessel and gear. The quantity of fuel used in harvesting is not available in the data set. A proxy variable is calculated based on a Cobb-Douglas aggregator function of vessel length, tonnage units, horsepower, and total catch levels (Diewert 1978). Each variable in the aggregator function receives equal weight (*i.e.*, 0.25). The price index for fuel (P_f) is then defined as the expenditure on fuel divided by the proxy variable measuring quantity of fuel. The vessel price index (P_v) is defined as expenditure on insurance and maintenance of the vessel and gear divided by the vessel's total catch level. Table 3 shows summary statistics for the two price indices for each year and by vessel type. Purse seine vessels incur the highest cost for fuel in all three years, followed by trawlers and coastal vessels. On the other hand, coastal vessels incur the highest costs for vessel and gear maintenance. The standard

Table 2
Observations per Vessel per Year

Year	1994	1995	1996
Purse seine	32	36	44
Trawler	34	32	37
Coastal vessel	53	49	56

Table 3
Input Price Indexes: Purse Seine, Trawler, and Coastal Vessel, 1994–96

Year	Vessel Type	Price Fuel	Price Vessel
1994			
	Purse seine	11.5 (3.15)	3.6 (1.2)
	Trawler	4.2 (1.14)	2.6 (1.3)
	Coastal vessel	1.4 (0.55)	5.7 (3.6)
1995			
	Purse seine	10.8 (3.02)	4.2 (1.5)
	Trawler	3.6 (0.99)	3.0 (1.6)
	Coastal vessel	1.34 (0.65)	6.8 (5.1)
1996			
	Purse seine	12.6 (3.20)	4.9 (2.1)
	Trawler	4.4 (1.75)	3.0 (1.5)
	Coastal vessel	1.50 (0.54)	5.9 (3.9)

Note: Mean values with standard errors in parentheses.

errors associated with the mean values of the price variables show substantial variation in input prices over time and across vessel types.

The data set available separates the harvest by spring-spawning herring, North Sea herring, mackerel, and other fish. All vessels harvest spring-spawning herring; however, not all vessels harvest the other species. As the interest of the study is on spring-spawning herring, it was decided to define the cost function over two outputs, spring-spawning herring (Q_{sh}) and other fish (Q_{of}), where other fish represents the total harvest of North Sea herring, mackerel, and other fish.

A measure of vessel capital is defined using the tonnage units for each vessel. In table 4, the quantity of fish harvested for the two different outputs and tonnage units, by vessel type and across years, is reported. Purse seine vessels are, by far, the largest vessels in the fleet and capture the largest harvest of both spring-spawning herring and other fish. Coastal vessels are the most numerous vessel type in the fleet, but harvest the smallest share of both spring-spawning herring and other fish. Trawlers are, on average, about 25% of the tonnage units of purse seine vessels, but they harvest as much as 65% of the purse seine catch, on average, particularly of other fish. However, much of this harvest is fish for reduction into fishmeal and oil.

In modelling the harvesting process, we assume that the vessel will attempt to minimize the cost *(C)* of fuel and other inputs to harvest a given catch level of spring-spawning herring and other fish, subject to vessel type and tonnage units. The cost minimizing problem is written as:

$$C(P, Q, T) = \min P_f q_f + P_v q_v : H(q_f, q_v, T, Q_{sh}, Q_o) = 0 \tag{1}$$

where P is the input price vector for fuel (f) and vessel (v), q is the corresponding measure of the quantity of inputs, Q is the harvest vector for spring-spawning herring (sh), and other (o) fish, T is the fixed factor capital measure of tonnage units, while $H(.)$ represents the harvest function. As is well known, solving the cost minimization problem generates a cost function in terms of input prices, output harvest quantities, and the fixed tonnage units or:

$$C = C(P_f, P_v, T, Q_{sh}, Q_o) \tag{2}$$

Table 4
Harvest (tons) and Tonnage: Purse Seine, Trawler, and Coastal Vessel, 1994–96

Year	Vessel Type	Harvest Spring-Spawning Herring	Harvest Other[a]	Tonnage Units
1994				
	Purse seine	1,766.6	6,970.3	734.0
	Trawler	633.36	3,452.9	189.9
	Coastal vessel	407.55	307.27	62.6
1995				
	Purse seine	2,845.9	4,934.5	718.8
	Trawler	785.16	4,332.7	177.6
	Coastal vessel	438.45	255.58	57.8
1996				
	Purse seine	3,677.7	5,965.6	779.7
	Trawler	1,051.0	2,805.3	180.5
	Coastal vessel	475.69	361.64	59.7

[a] North Sea herring, mackerel, and other fish.

For estimation, each right-hand side variable is centered on the mean of the variable in 1994.

For estimation, the trans-log flexible functional form is used to specify $C(.)$ in equation (2). The trans-log is often used in empirical work and is not encumbered by restrictions on substitution possibilities and regularity conditions compared to say, the Cobb-Douglas form (Brown and Christensen 1981).[5] The estimating equation for the trans-log functional form is written as:

$$\begin{aligned}\ln C = {} & \ln \alpha_o + \sum_{i=1}^{n} \alpha_i \ln P_i + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \gamma_{ij} \ln P_i \ln P_j + \alpha_{Qs} \sum_{s=1}^{m} \ln Q_s \\ & + \frac{1}{2} \sum_{s=1}^{m} \sum_{k=1}^{q} \gamma_{sk} \ln Q_s \ln Q_k + \frac{1}{2} \sum_{i=1}^{n} \sum_{s=1}^{m} \rho_{is} \ln P_i \ln Q_s + \gamma_T \ln T \\ & + \frac{1}{2} \gamma_{TT} \ln T^2 + \sum_{i=1}^{n} \rho_{iT} \ln P_i \ln T + \sum_{s=1}^{m} \gamma_{sT} \ln Q_s \ln T + e \end{aligned} \tag{3}$$

where C is the variable cost of fuel and maintenance, $i = f$ (fuel cost), and v (vessel and other cost), $s = sh$ (spring herring), and o (other fish), T is the tonnage units for the vessel, and e is a random error assumed to be normally distributed. Equation (3) is combined with the cost-share equation for fuel, and estimation is carried out using a weighted, iterative seemingly unrelated regression procedure. The share equation regresses the expenditure share of fuel in total cost on the log of the price of fuel, price of vessel maintenance, tonnage units, harvest level of spring-spawning herring and other fish. A weighted, iterative seemingly unrelated regression estimator is used to correct for heteroskedasticity caused by different vessel size.

Input demand elasticities, economies of scale, and output cost elasticities can be calculated from the parameters of equation (3) (Caves, Christensen and Swanson 1981). Input demand elasticities are defined as:

[5] See Gordon (1987) for a discussion of the limitations of using a multi-output Cobb-Douglas functional form.

$$\varepsilon_{ij} = \frac{\gamma_{ij} + S_i S_j}{S_i}, \; i, j = f, v \tag{4}$$

A measure of economies of scale for a two-output, short-run cost function is calculated for each vessel type using:

$$ES = (1 - \partial \ln C / \partial \ln T)/(\partial \ln C / \partial \ln Q_{sh} + \partial \ln C / \partial \ln Q_{of}) \tag{5}$$

Finally, cost elasticity with respect to each output at mean 1994 levels is computed as:

$$\eta_{cs} = \alpha_{Qs}, \; Qs = Q_{sh}, Q_o \tag{6}$$

Our research approach is to carry out preliminary estimation using the Cobb-Douglas functional form for the cost equation and test for yearly significant differences in the data series. We are concerned that yearly changes in the stock of fish or weather conditions might have a statistically important influence in changing the parameters in the estimated cost function. Testing was carried out using yearly dummy variables for the intercept and slope coefficients, but the results showed no significant yearly changes in the cost parameters. Based on this result, the yearly data were pooled for further investigation using the trans-log functional form.

The estimated parameters of the cost function, along with their standard errors, are reported in tables 5.1, 5.2, and 5.3 for purse seine, trawler, and coastal vessels, respectively. The trans-log cost function appears to fit the data reasonably well, with estimated coefficients statistically significant at standard levels. The estimated model satisfies the cost regularity conditions at mean 1994 values. The own-price elasticity estimates for each vessel type for each year with associated standard errors are listed in table 6. The fuel price elasticity is reported in column three, and the vessel price elasticity is reported in column four. Purse seine vessels are estimated to have a more inelastic response to both fuel and vessel prices, as compared to either trawlers or coastal vessels. Nonetheless, all vessel types show a strong inelastic response to prices, and there appears to be very little variation in these values over the three-year period for each vessel type. This implies a rigid input structure for all vessel types, particularly for purse seine vessels (Bjørndal and Gordon 1993).

Table 5.1

Purse Seine: Trans-Log Cost Function: Estimates and Standard Errors (S.E.)

Parameter	Estimate	S.E.	Parameter	Estimate	S.E.
Constant	15.26	0.004	ρ_{fsh}	–0.021	0.012
α_f	0.262	0.005	ρ_{fo}	0.004	0.012
α_v	0.738	0.004	ρ_{vsh}	0.033	0.011
α_{ff}	0.144	0.009	ρ_{vo}	0.079	0.010
α_{vv}	0.144	0.009	γ_T	0.145	0.012
α_{fv}	–0.144	0.009	γ_{TT}	0.172	0.039
α_{sh}	0.144	0.012	ρ_{fT}	0.012	0.021
α_o	0.653	0.009	ρ_{vT}	–0.107	0.017
γ_{shsh}	0.269	0.032	γ_{shT}	–0.844	0.029
γ_{oo}	0.236	0.017	γ_{oT}	–0.104	0.021
γ_{sho}	–0.151	0.017			

Note: *f* is fuel, *v* is vessel maintenance, *sh* is spring-spawning herring, *o* is other fish, and *T* is tonnage units.

Table 5.2
Trawler: Trans-Log Cost Function: Estimates and Standard Errors (S.E.)

Parameter	Estimate	S.E.	Parameter	Estimate	S.E.
Constant	14.19	0.005	ρ_{fsh}	–0.018	0.018
α_f	0.280	0.006	ρ_{fo}	0.010	0.013
α_v	0.719	0.006	ρ_{vsh}	0.009	0.015
α_{ff}	0.082	0.009	ρ_{vo}	0.022	0.009
α_{vv}	0.082	0.009	γ_T	0.074	0.017
α_{fv}	–0.082	0.009	γ_{TT}	0.083	0.059
α_{sh}	0.154	0.011	ρ_{fT}	–0.014	0.025
α_o	0.704	0.009	ρ_{vT}	–0.011	0.021
γ_{shsh}	0.249	0.059	γ_{shT}	–0.063	0.055
γ_{oo}	0.194	0.014	γ_{oT}	–0.044	0.029
γ_{sho}	–0.131	0.028			

Note: *f* is fuel, *v* is vessel maintenance, *sh* is spring-spawning herring, *o* is other fish, and *T* is tonnage units.

Table 5.3
Coastal Vessel: Trans-Log Cost Function: Estimates and Standard Errors (S.E.)

Parameter	Estimate	S.E.	Parameter	Estimate	S.E.
Constant	13.26	0.006	ρ_{fsh}	0.001	0.006
α_f	0.266	0.005	ρ_{fo}	–0.013	0.009
α_v	0.734	0.005	ρ_{vsh}	0.035	0.006
α_{ff}	0.094	0.009	ρ_{vo}	0.051	0.009
α_{vv}	0.094	0.009	γ_T	0.119	0.007
α_{fv}	–0.094	0.009	γ_{TT}	0.048	0.023
α_{sh}	0.434	0.006	ρ_{fT}	–0.032	0.011
α_o	0.351	0.006	ρ_{vT}	–0.041	0.011
γ_{shsh}	0.152	0.005	γ_{shT}	–0.019	0.011
γ_{oo}	0.166	0.008	γ_{oT}	–0.041	0.011
γ_{sho}	–0.134	0.007			

Note: *f* is fuel, *v* is vessel maintenance, *sh* is spring-spawning herring, *o* is other fish, and *T* is tonnage units.

The fifth column in table 6 reports estimates of economies of scale for each vessel type and for each year. In general, all vessel types show increasing returns to scale in all three years. It is interesting, however, that the purse seine and trawler vessel groups appear to have captured much of the benefits available in terms of cost reductions due to scale effects (*i.e.*, scale measures close to one). Whereas, for coastal vessels substantial cost benefits could still be achieved by allowing individual vessels to increase harvest levels and capture the available economies of scale.

Finally, table 7 shows the cost elasticities associated with each output group for each vessel type. The table shows substantial variation in the response of total cost to changes in harvest levels across the different vessel groups. The cost elasticity measure for spring-spawning herring is smallest for purse seiners, then trawlers, and finally, coastal vessels. In both cases, spring-spawning herring and other fish, we measure an inelastic response of total cost to changes in harvest levels. It is likely that this result can be attributed to the fact that Norwegian spring-spawning herring

Table 6
Input Price Elasticities and Economies of Scale:
Purse Seine, Trawler, and Coastal Vessel, 1994–96

Year	Vessel Type	Fuel Elasticity	Vessel Elasticity	Economies of Scale
1994				
	Purse seine	–0.189 (0.04)	–0.067 (0.01)	1.073 (0.01)
	Trawler	–0.427 (0.03)	–0.166 (0.01)	1.080 (0.02)
	Coastal vessel	–0.380 (0.03)	–0.138 (0.01)	1.121 (0.01)
1995				
	Purse seine	–0.179 (0.04)	–0.059 (0.02)	1.041 (0.01)
	Trawler	–0.438 (0.04)	–0.152 (0.01)	1.050 (0.02)
	Coastal vessel	–0.381 (0.04)	–0.126 (0.01)	1.102 (0.01)
1996				
	Purse seine	–0.181 (0.05)	–0.052 (0.01)	1.023 (0.01)
	Trawler	–0.452 (0.03)	–0.162 (0.01)	1.068 (0.02)
	Coastal vessel	–0.393 (0.03)	–0.133 (0.01)	1.116 (0.01)

Note: Standard errors in parentheses.

Table 7
Cost Elasticity with Respect to Each Output Group

Output Group	Spring-Spawning Herring	Other Fish
Purse seine	0.144 (0.01)	0.653 (0.01)
Trawler	0.154 (0.11)	0.704 (0.02)
Coastal vessel	0.435 (0.01)	0.351 (0.02)

Note: Mean values with standard errors in parentheses.

is a schooling fish stock. With modern fish-finding equipment, schooling fish are fairly easy to locate and harvest even as stock size declines. As a consequence, unit harvesting cost may remain fairly constant (Bjørndal 1988).

The elasticity summary measures provide an interesting description of the Norwegian spring-spawning herring fleet, but a visual representation of the different cost characteristics will allow us to clearly differentiate costs across vessel types. Figure 1 graphs out the estimated average cost of harvesting spring-spawning herring for each vessel type. The estimates are calculated by holding constant all variables at mean levels in 1994, except harvest levels of spring-spawning herring. Based on this, short-run costs are calculated for the actual range of harvest levels of spring-spawning herring for each vessel type. Short-run costs are then divided by the sum of the mean level of other fish harvested for that vessel type in 1994 and the harvest level of spring-spawning herring. Average costs are measured per ton of fish captured.

The most notable point in figure 1 is the high-cost of harvesting for coastal vessels compared to trawlers and purse seiners. The largest coastal vessel is capturing about 1,400 tons of spring-spawning herring, and at mean levels of other fish harvested achieves an average cost of about 650 NKr per ton. On the other hand, trawlers are the most efficient vessels in the fleet, achieving an average cost of 455 NKr per ton of harvest at a catch level of 1,600 tons of spring-spawning herring. Purse

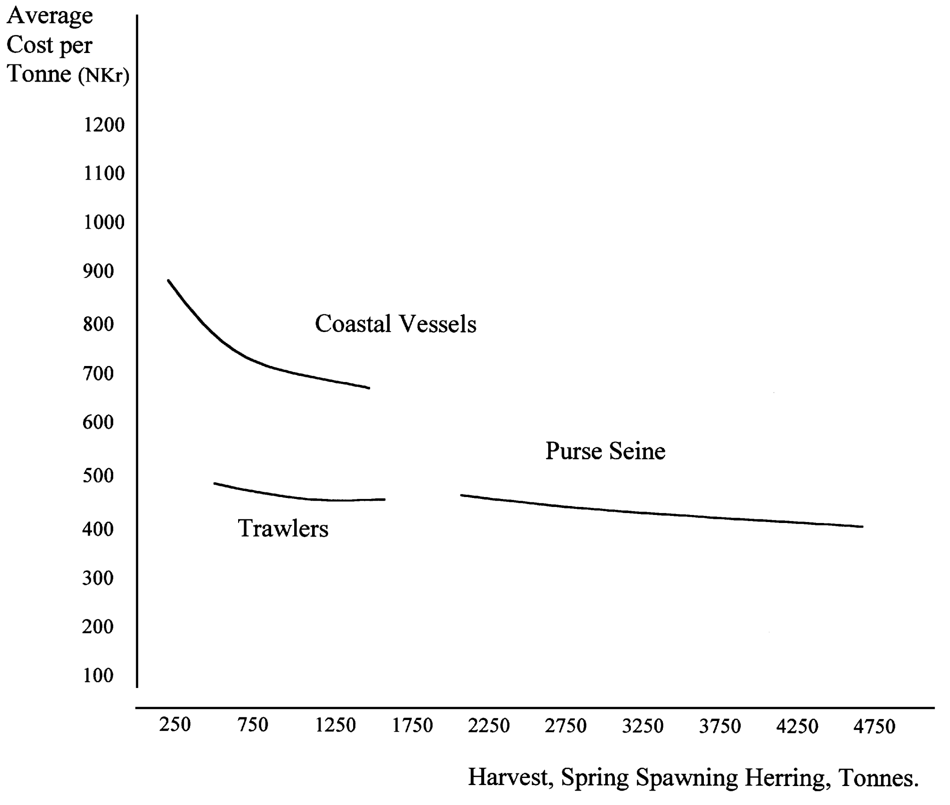

Figure 1. Estimated Average Cost by Vessel Type, at Mean 1994 Levels, NKr per Ton

seine vessels certainly capture the largest share of the spring-spawning harvest, but achieve an average cost of 480 NKr per ton at a harvest level of about 4,650 tons. The figure shows trawlers and purse seine vessels with a very flat average cost curve compared to coastal vessels and seems to have captured available economies of scale to this technology. Again, we attribute this to the schooling nature of spring-spawning herring (Bjørndal 1988).

Conclusion

The purpose of this paper is to measure the economic cost of harvesting spring-spawning herring by three vessel types, purse seiners, trawlers, and coastal vessels. The data available for analysis allow for cost estimates of the different technologies used in harvesting. The statistical results appear to provide reasonable estimates of the three different harvest technologies. Purse seiners and trawlers are cost efficient in terms of capturing available economies of scale; however, trawlers take only a small share of the harvest relative to purse seiners. The scale results for purse seiner vessels are very interesting and show that, despite substantial changes in stock size and output per purse seiner, cost per kg is fairly constant across this group. This is an important result that makes bioeconomic modelling of the stock easier.

Coastal vessels are measured to suffer substantial harvesting inefficiencies, and at best, incur average costs 30% higher than purse seiner vessels. As all three vessel types receive a regulated share of the total harvest, the substantial differences in harvest efficiency, especially between purse seiners and coastal vessels, may introduce a serious form of rent dissipation in the Norwegian fisheries. Dupont 1990 argues that this form of rent dissipation is caused by a ‘sub-optimal mix of heterogeneous vessels’ and is perpetuated by government policy that allows inefficient vessels to continue fishing. As we only investigate the cost of harvesting, and not the revenue received for the harvest or the technical requirements for inshore coastal fishing compared to the open seas, we cannot argue for a reduction in quota levels for coastal vessels. However, the importance of government regulation in maintaining the large numbers of these high-cost vessels is an interesting question, and should be investigated further.

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