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Variable unit costs in output regulated fisheries

by

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Abstract

Departing from general cost theory of the firm and bioeconomic theory of the fishery, this paper contributes with an empirical examination of how variable unit costs in a Norwegian demersal and pelagic fishery depend on output and biomass. The identification of the separate effects that the two factors have on costs is not common in the literature. Three Norwegian fleets fishing Norwegian spring spawning herring and five Norwegian fleets fishing Northeast Arctic cod are evaluated. The findings indicate that variable unit costs fall in output in both fisheries. The results also show that variable unit costs fall in biomass in the demersal fishery, but with a stock elasticity significantly less than 1. These results are of relevance to a manager seeking the optimal harvest rule and to understand fishermen's incentives when individual vessel quotas are reduced.

1. Introduction

In the Northeast Atlantic, a number of marine fish stocks are managed by harvest rules that specify annual output in the form of a Total Allowable Catch (TAC). The TACs are subsequently broken down by nation, fleet and ultimately as individual vessel quotas (IVQs). This paper addresses how variable unit costs in an IVQ-regulated herring and cod fishery are affected by output and the size of the relevant fish stock. These two fisheries come close to two common stylised fisheries often encountered in the literature as respectively, (i) a pelagic fishery where the unit costs are assumed to be independent of stock size (Bjørndal, 1987 and 1988) and (ii) a demersal fishery where the unit costs are assumed to be proportional to the size of the fish stock (Schaefer, 1957).

When unit costs are assumed independent of stock, it is possible to estimate how output affects costs, but the results are critically dependent on the assumption of no stock effect. Likewise, when estimating how costs are affected by stock, it is often implicitly assumed that they are independent of output, an assumption of critical importance for the stock effect measured. In this paper both output and biomass are treated as explanatory variables for costs, and their parameters are estimated simultaneously.

Faced with output controls, the individual firms will have an incentive to minimise costs in order to maximise profits. Incomplete markets for input factors, asymmetric information and skills between the operators of the vessels may, however, lead to large variation in costs, and therefore efficiency, across vessels. Several authors have addressed efficiency questions that involve the use of either stochastic production frontier (SPF) or data envelope analysis (DEA). Kirkley *et al* (1995) have applied SPF to study questions of efficiency in fisheries, whereas Kirkley *et al* (1998) have used the same methodology to assess managerial skill (in a fishery). Grafton *et al* (2000) use SPF to assess efficiency gains of the introduction of individual transferable quotas in a fishery. Coelli (1995) gives a general overview of the method of SPF and DEA. In contrast to the papers by Kirkley *et al*, and Grafton *et al*, the current paper focuses explicitly on how output and stock size affect variable unit costs across vessels in the fishery, regardless of whether the vessels perform on the production frontier.

The motivation for the work is the common knowledge that alternative harvest rules differ in respect of output (quotas) and biomass (fish stock left in sea after harvesting). Such differences will affect both efficient and less efficient vessels. Knowledge of how variable unit costs are affected by output and biomass (the output and stock elasticities) has relevance for the choice of optimal harvest rule (e.g. target escapement).

We start out by identifying relevant issues regarding costs in output-regulated fisheries. Panel data drawn from the Norwegian fisheries on Norwegian spring spawning herring and Northeast arctic cod are presented in section 3. The estimation strategy is given in section 4 and results in section 5. Concluding remarks are provided in section 6.

2. Costs in the fishery

When output in an industry is constrained, dual theory tells us that cost minimisation is a necessary condition for profit maximisation. The cost of production will then depend on the output level, cost function and prices in the input markets.

In the fishery, it is well known that the fish stock is an important production factor, see Gordon (1954) and Clark (1976). Contrary to other input factors, its size is beyond the control of the single firm in the industry and can be considered external. To the fishery, the cost of production therefore also depends on the size of the fish stock. In its most general form, the cost of fishing for a firm can be expressed in symbols as:

$$C = f(W, Y, X, S) \tag{1}$$

where

C : Costs
W : Prices of input factors
Y : Output
X : Biomass
S : Skill of owner/skipper/crew and physical characteristics of vessel

As equation (1) expresses, one of the factors that influences costs in an output-regulated fishery is the output level (Y), or the annual IVQ. At production levels below production capacity, as defined by fixed production factors, it seems reasonable to assume that variable costs to a firm will increase proportionally with the production level. Considering the overcapacity in the Norwegian fishing fleet (and in the world as well, see Kirkley and Squires (1998)), it can be expected that production restrictions usually are set well below production capacity. When production capacity is encountered, one would assume that variable costs would increase at a higher rate than production. Hence, at production levels below production capacity, variable costs per unit should be constant, whereas they should increase once production capacity becomes a constraint.

The existence of variable set-up costs may modify this picture. In the fishery, vessels will be going back and forth between the dock and their fishing grounds. These trips will imply a necessary set-up cost before the harvest process, and the total set-up costs throughout a year will depend on the number of trips necessary to produce the annual IVQ. With incentives to minimise costs, it is reasonable to assume that the length of each trip will be optimised to a specific level. Holding the external production factor (the fish stock) constant, so that catch rates do not vary, the number of trips each year should vary proportionally with the size of the annual IVQ. However, if the number of trips, for some reason or other, increases at a slower rate than an increase in the IVQ (indicating that the vessel will stay longer on the fishing ground at high IVQ than at low IVQ) the variable unit cost in the fishery may be decreasing in output.

The other factor that influences costs is the fish stock (X). The fish stock will influence variable unit costs if its size influences catch rates. An underlying assumption in the model developed by Schaefer (1957) is that there is a direct proportionality between the size of the fish stock and the catch per unit effort (CPUE). The intuition behind the idea is that if a fish stock has a uniform and constant spatial distribution, an increase of the biomass by 10% will increase the density of the stock and the CPUE by the same magnitude. This relation is often assumed in demersal fisheries. Holding the output (IVQ) in a demersal fishery constant, one would therefore often assume variable costs per unit output to be proportionally decreasing in biomass.

In schooling species like herring, proportionality between stock size and CPUE is less obvious. In the literature it is either assumed, or found (Bjørndal, 1987, 1988) that there is no, or only a weak, relationship between stock size and CPUE. The intuition behind this assumption is that herring concentrates in schools and thus has no uniform distribution over an area. Once the vessel has targeted a school of herring, the catch during the harvest operation may be unaffected by the size of the fish stock. On the other hand, if a reduction of a herring stock implies that the vessels will spend more time searching for the schools, a relationship between stock size and cost per unit output is to be expected.

Equation (1) further states that cost to the individual firm will depend on prices of input factors (W) and individual effects (S). For the fisheries analysed in this paper it is reasonable to assume that the firms are price takers in the input market, and in the empirical analysis we will assume constant real prices in these input markets.

Individual effects may cause variation in costs across vessels, and be caused either by vessel characteristics or by skill of owner/skipper/crew, see Kirkley *et al* (1998). It is natural to assume that the vessel characteristics will be fixed for longer periods than the skill of the labour that owns and operates the vessel, but this depends on how often a vessel is sold or a captain or crew is replaced. These differences in costs between vessels caused by individual effects are of special interest when analysing efficiency in the fishing fleet, but they are not of primary interest when assessing how output and stock size affect variable unit costs across vessels in a fishery.

Generally, fisheries may target single species or a blend of species. In the latter case, the vessels can be seen as firms producing several outputs, but where the input factors are the same for each species. Squires and Kirkley (1991) characterise such a multi output production as *"joint in inputs"*. The cost of producing one of the species in a multi-output production may then depend on the production of another species if cost complementarities exist.

Consequently, in a paper analysing the effect of trip quotas[1], Squires and Kirkley (1991) argue that "effective quotas for regulating multiproduct firms require information on the structure of technology and costs". Constraining the catch of one species in a multi-species production will give the firms incentives either to stop fishing, or to continue fishing and discard the regulated species. In a study of a Pacific coast trawl fishery, it is found " that when the trip quotas (for sablefish) tighten, the firm cannot sufficiently reorganise its product bundle to preclude increasingly large sablefish disposal" (Squires and Kirkley, 1991, page 122). The authors conclude that

[1] The difference between an annual IVQ, as discussed in this paper, and a trip quota is that the former regulates annual output, whereas the latter regulates output per trip.

inputs to catch sablefish are joint for this and several other species. In a survey article, Jensen (2002) discusses technological and economic features in fisheries and compares results from 12 different studies. Nine of these studies report that production is joint in inputs.

The Norwegian cod and herring fisheries, whose costs will be evaluated in this paper, differ in respect of technology. In the cod fishery, there may be bycatches of other demersal species, but the quantity of the bycatch is limited. In the herring fishery, there is no bycatch. With the limited bycatch in the cod fishery, the input used in both fisheries will be considered as nonjoint to the production of other species.

3 Data on costs, output (catch) and biomass

Annual cost and catch data at vessel level for the 11-year period 1990-2000 collected by the Norwegian Directorate of Fisheries are used in the estimation. In addition, data on biomasses of cod and herring for the same years are taken from the International Council for the Exploration of the Seas (ICES, 2003).

3.1 Data on costs and output

A panel set of cost and catch data at the vessel level are used. Of all the fleets combined, only a few vessels (14) report cost figures each year, making the data set unbalanced. The vessels are grouped according to fleet, and the fleets are distinguished on the basis of vessel size, gear, or onboard production facilities. Appendix A gives a description of the various vessel groups. Table 1 shows the frequency of reports and the number of observations within each fleet.

Table 1 *Unbalanced panel data set for Norwegian vessel groups fishing Norwegian spring spawning herring and Northeast Arctic cod during the 11-year period 1990 – 2000.*

Frequency	Coastal vessels (herring)	Purse seiners (herring)	Pelagic trawlers (herring)	Coastal vessels below 21 metres (cod)	Coastal vessels above 21 metres (cod)	Long Liners above 28 metres (cod)	Fresh fish trawlers (cod)	Factory trawlers (cod)
1	130	20	30	169	39	20	20	1
2	65	15	22	87	22	13	20	0
3	30	32	8	51	14	19	17	4
4	20	10	6	44	8	10	10	3
5	12	13	6	30	3	4	6	1
6	7	9	5	19	4	5	13	4
7	11	9	3	12	1	7	9	3
8	4	8	4	9	0	1	3	0
9	1	3	0	3	2	2	4	1
10	1	7	0	1	0	3	0	3
11	0	3	0	0	0	1	5	5
Number of vessels.	281	129	84	425	93	85	107	25
Number of observations	660	562	235	1129	221	309	437	169

Operating cost items are defined as items necessary to operate the vessel in the short term. Quasi-fixed cost items are defined as items necessary within a period of a year. The fixed cost items are defined as costs of the vessel (depreciation and financial costs)[2]. In the long run, all these items will be variable and chosen in order to minimise the costs necessary to produce the output. When the output from the vessel is constrained by an annual quota, it seems reasonable to assume that firms will minimise operating costs and costs of quasi-fixed input factors, but how these two cost categories depend on output and biomass levels may differ.

With the exception of labour costs, the market value of each input factor will be used as a proxy for the corresponding opportunity cost. Although wages/share to crew reflect labour cost to the owner of the vessel, these cannot be expected to reflect labour's opportunity cost to society because they vary as a fixed percentage of the value of the catch. Thus, a substitute, based on reported number of man-years utilised on the vessel during a period (a year) multiplied by a figure for the value of a man-year, is used. The actual figure is based on the cost of a man-year in the construction industry (Statistics Norway, 2003).

3.1.1 Data on relevant cost items

From the panel data as shown in Table 1, operating costs and quasi-fixed costs, as identified in Appendix B, were collected. The vessels report these figures annually, and they reflect the annual cost of all fisheries in which the vessel has been engaged. There is consequently a need to disentangle the cost of relevance to the fisheries evaluated in this paper, and the method for doing this is presented in Appendix C. The data span an 11-year period and were normalised to the real price level in year 2000 by the consumer price index (CPI)[3]. Tables B2 and B3 in Appendix B show the annual average values of the sum of operating and quasi-fixed costs in the herring and cod fishery, respectively.

3.1.2 Data on output (catches)

For the panel data described in Table 1, the average catch at vessel level for herring is given in Table B4 in Appendix B. The corresponding figures for cod are given in Table B5.

3.2 Data on biomass levels

The International Council for the Exploration of the Seas collects time series data on the biomass of cod and herring. In the herring fishery, the fleets are only targeting the Spawning Stock Biomass (SSB). In the cod fishery, coastal vessels target the SSB,

[2] See Table B1 in Appendix B for a detailed classification of various cost items.

[3] The annual cost items are given in nominal figures. The CPI is a deflator that standardises the purchasing power, and thus the opportunity cost, of using a historical monetary value. Applied on the monetary value of input factors used in the fishery, the CPI thus standardises the opportunity costs of these input factors to society.

whereas the trawlers target a wider range of year-classes, in which case Total Stock Biomass (TSB) is the better measure of the fishable stock. Figure 1 shows the development of SSB of herring and the TSB/SSB of cod for the period 1990-2000. Corresponding figures are given in Appendix B, Table B6.

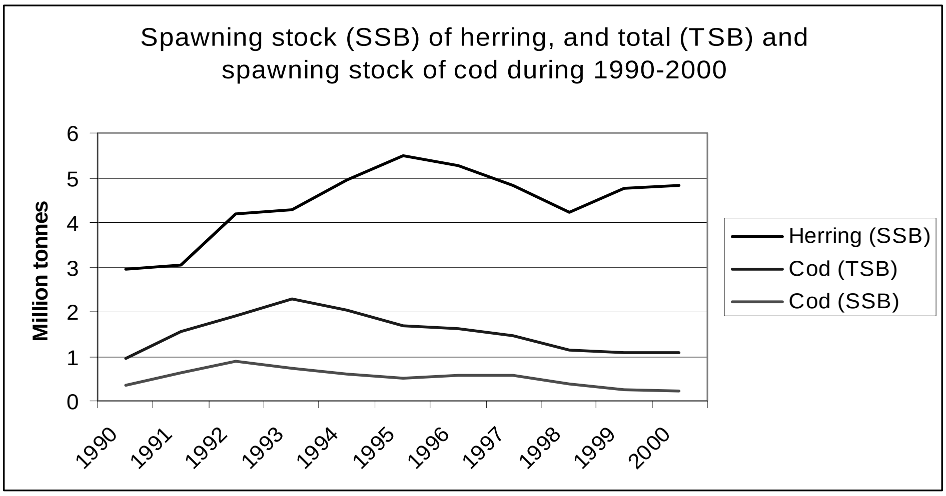

Figure 1 Development of cod and herring during the period 1990-2000

With these data we will proceed to estimate how variable unit costs depend upon output and biomass. The strategy for this estimation is given in the next section.

4 Estimation strategy

As discussed in section 2, the cost in an output-regulated fishery is expected to depend on output, biomass, the price of the input factors, as well as the skills of the owner/skipper/crew and the physical characteristics of each vessel. Assuming constant real prices in the input markets, the functional relationship for the variable costs of an individual vessel can be expressed as:

$$C_{i,y} = f(Y_{i,y}, X_y, S_i) \tag{2}$$

where

$C_{i,y}$: Variable costs for vessel **i** in year **y**

$Y_{i,y}$: Catch for vessel **i** in year **y**

X_y : Biomass in year **y**

S_i : Skill of owner/skipper/crew and physical characteristics of vessel

It might be expected that catch (Y) and biomass (X) would be correlated, causing problems of multicollinearity, in which case it will be difficult to estimate independent parameters for catch and biomass. Variance inflation factors (vif) were calculated (see Table 2) and showed generally no serious problems of multicollinearity[4]. This is probably the result of the output regulation in these fisheries. In contrast to an input regulation, the output restriction each year is based on the real-time assessment of the stock and existing objectives set by the managers. The annual assessment of the stock is uncertain and its accuracy improves over time. The data representing biomass in this analysis are drawn from an assessment of the time series 1990-2000 as given in ICES (2003), and they differ quite strongly from what these spawning stock levels were assessed to be in real time. In addition, the objectives of the managers resulting in a realised vessel quota may have varied throughout the period. Finally, the vessel quotas will vary according to size of the vessel (Aarland and Bjørndal, 2002).

Both Y and X can be measured, whereas S cannot. If S is correlated with the other explanatory variables, estimation by ordinary least squares (OLS) will yield biased results, i.e. the omitted variable problem. The individual vessel quota for the various species is to a great extent determined by the physical characteristics of the vessel (licensed capacity, length or tonnage). To obtain non-biased estimates of the effects of catch and stock on the cost, the unobserved effect of S needs special treatment.

One way forward would be to include a regressor showing some physical characteristics of the vessel, such as licensed capacity, length or tonnage. This could accommodate effects of the physical characteristics of the vessel, but not effects from the skill of the owner/skipper/crew. Another way forward would be to neutralise the unobserved effect of S by the fixed effect method. In the current analysis, this can be justified because our primary interest is on the effects that output and stock biomass may have on unit costs. This technique is equivalent to assigning dummies for the vessels, an approach that will be used in this paper.

4.1 Identification of variable costs

The variable costs have been described as quasi-fixed and operating costs. Both categories are variable within the time period of relevance for the regulatory tool (a year). The operating costs will occur in each specific fishery, whereas the quasi-fixed costs occur as a consequence of all the fisheries in which the vessel has participated. One should therefore expect that consequences of output and biomass on operating and quasi-fixed costs differ.

To evaluate this, the dependence of either operating costs or the sum of operating costs and quasi-fixed costs on output or biomass levels will be examined.

[4] A variance inflation factor (VIF) is 1/(1-R_k^2), where R_k^2 is the coefficient of correlation between two explanatory variables. A high VIF indicates problems of multicollinearity.

4.2 Model specification

The focus of this paper is to assess how variable unit costs can be explained by output and the production factor external to the individual firm – the fish stock. If the fish stock (X) is constant, changes in variable costs should be affected by output (Y) only. However, if there is also variation in the fish stock, this may affect catch rates at all output levels. In such a production process, it is reasonable to assume that these variables affect variable costs multiplicatively[5]. The variable cost of a single vessel in a specific year can then be described as:

$$C_{i,y} = \alpha Y_{i,y}^{\ \beta_1} X_y^{\ \beta_2} S_i^{\ \beta_3} \varepsilon_{i,y} \tag{3}$$

where:

$\varepsilon_{i,y}$: lognormally distributed error term

To find the unit cost in the fishery, (3) is divided by Y

$$C_{i,y} / Y_{i,y} = \alpha Y_{i,y}^{\ \beta_1 - 1} \ X_y^{\ \beta_2} S_i^{\ \beta_3} \varepsilon_{i,y} \tag{4}$$

which may be written as

$$\overset{*}{C}_{i,y} = \alpha Y_{i,y}^{\ \overset{*}{\beta}_1} X_y^{\ \beta_2} S_i^{\beta_3} \varepsilon_{i,y} \tag{5}$$

The unobserved (fixed) effect of S is removed by dummy technique, so the equation estimated is:

$$\overset{*}{C}_{i,y} = \alpha Y_{i,y}^{\ \overset{*}{\beta}_1} X_y^{\ \beta_2} \varepsilon_{i,y} \tag{6}$$

Inspection of catch data revealed that for one of the vessel groups, the purse seiners, there was a need to introduce a dummy variable to account for changes in fishing areas. Purse seiners whose home port are in the southern part of Norway changed fishing areas during the period. When the stock was at a relatively low level (in 1990 and 1991), these purse seiners caught the majority of their annual harvest along the coast of southern Norway. When the stock increased, the fishing areas were moved to the coast of northern Norway. As these purse seiners deliver nearly all their catch to processors in southern Norway or abroad (mostly Denmark), a shift northwards of fishing areas implies higher fuel costs.

Norwegian spring spawning herring is available along the coast of southern Norway during spring (when it spawns) and along the coast of northern Norway during late

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[5] Weninger (1998) utilises a translog function to estimate variable cost in a mixed fishery on Surf Clam and Ocean Quahog. A translog cost function is also utilised by Bjørndal and Gordon (2001) when estimating cost functions for the fishery on Norwegian spring spawning herring. The advantage of using a translog cost function is that few implicit restrictions are put on its form, and it allows for modelling second order effects such as elasticity of substitution. The modelling of such effects or a cost function in general is, however, not a key point in the current paper.

fall. A change in fishing areas towards the coast of northern Norway thus reflects a change of season for the herring fisheries from spring to late autumn. It is not clear what caused a shift of fishing areas and seasons during the period, but changed effort in other fisheries (capelin and blue whiting) may have been major factors. Nevertheless, for the purse seiners, a dummy variable, d , was entered to take account of the changed area of fishing[6], and the following equation was estimated:

$$\overset{*}{C}_{i,y} = \alpha Y_{i,y}^{\overset{*}{\beta}_1} X_y^{\beta_2} d^{\beta_3} \varepsilon_{i,y} \tag{7}$$

In the next section, results of (6) and (7) are presented and discussed.

5 Results and discussion

Table 2 shows the estimated parameters of (6) and (7) when $\overset{*}{C}$ represent the sum of operating and quasi-fixed unit costs. Table 3 shows the corresponding parameters when $\overset{*}{C}$ represents R2 (fuel and lubrication oil) in the herring fishery and R2 and R4 (bait, ice, salt and packing) in the cod fishery. Thus the parameters shown in Table 2 show how changes in output or biomass affect the sum of operating and quasi-fixed unit costs, whereas the parameters in Table 3 show how changes in output or biomass affect specific operating costs per unit. By comparing these sets of parameters it is possible to detect whether exclusion of quasi-fixed costs will influence the parameter values strongly.

[6] The dummy variable was given a value of zero for 1990 and 1991, and one for the years 1992-2000.

Table 2 Parameter estimates of $\alpha, \overset{*}{\beta}_1, \beta_2$ *and (* β_3 *) in equation 6 and (7). The dependent variable* $\overset{*}{C}$ *consists of operating and quasi-fixed costs.* $\overset{*}{\beta}_1$ *is the elasticity of cost with respect to output,* β_2 *is the elasticity of cost with respect to biomass and* β_3 *is the effect of the dummy variable. (s.e.) reflects standard error.*

Fishery	Fleet	α (s.e.)	$\overset{*}{\beta}_1$ (s.e.)	β_2 (s.e.)	β_3 (s.e.)	Variance inflation factor	R^2
Herring	Coastal	22.00 (2.21)	-0.35 (0.04)	-0.66 (0.17)		1.42	0.76
Herring	Purse seine	16.21 (2.88)	-0.10 (0.03)	-0.52 (0.20)	0.37 (0.13)	4.94	0.40
Herring	Pelagic trawl	17.35 (5.36)	-0.29 (0.08)	-0.43 (0.39)		1.67	0.64
Cod	Coastal, 13-21 m	17.14 (0.65)	-0.48 (0.04)	-0.21 (0.04)		1.00	0.85
Cod	Coastal, 21-28 m	14.67 (0.97)	-0.26 (0.06)	-0.21 (0.07)		1.01	0.79
Cod	Long liners	14.88 (1.46)	-0.28 (0.10)	-0.18 (0.04)		1.07	0.60
Cod	Fresh fish trawlers	18.65 (0.74)	-0.22 (0.04)	-0.50 (0.06)		1.02	0.71
Cod	Factory trawlers	20.33 (1.35)	-0.22 (0.06)	-0.59 (0.09)		1.06	0.58

Table 3 Parameter estimates of $\alpha, \overset{*}{\beta_1}, \beta_2$ and (β_3) in equation 6 and (7). The dependent variable $\overset{*}{C}$ consists of fuel and lubrication oil in the herring fishery (R2 in Table B1), as well as bait, ice, salt and packing in the cod fishery (cost items R2 and R4 in Table B1). $\overset{*}{\beta_1}$ is the elasticity of cost with respect to output, β_2 is the elasticity of cost with respect to biomass and β_3 is the effect of the dummy variable. (s.e.) reflects standard error.

Fishery	Fleet	α (s.e.)	β_1 (s.e.)	β_2 (s.e.)	β_3 (s.e.)	R^2
Herring	Coastal	22.87 (2.36)	-0.49 (0.05)	-0.77 (0.18)		0.79
Herring	Purse seine	7.71(3.49)	-0.23 (0.03)	0.02 (0.24)	0.26 (0.14)	0.46
Herring	Pelagic trawl	15.17 (5.80)	-0.47 (0.08)	-0.25 (0.42)		0.71
Cod	Coastal, 13-21 m	13.26 (0.77)	-0.53 (0.05)	-0.08 (0.05)		0.82
Cod	Coastal, 21-28 m	11.48 (1.20)	-0.57 (0.07)	0.13 (0.09)		0.78
Cod	Long liners	14.54 (1.43)	-0.32 (0.10)	-0.26 (0.04)		0.68
Cod	Fresh fish trawlers	15.08 (0.90)	-0.31 (0.06)	-0.31 (0.07)		0.66
Cod	Factory trawlers	15.84 (1.31)	-0.37 (0.05)	-0.26 (0.08)		0.58

The explanatory power of equation (6), measured as R^2, varies between 0.58 and 0.85, whereas the explanatory power of (7), the purse seiners, are 0.40. Thus, output and biomass explain between 40 and 85% of the variation in variable unit costs.

When variable unit costs are defined as operating and quasi fixed costs (Table 2) all parameters, except β_2 (the stock effect) for the pelagic trawlers, were found to be significant at the 95% level. When costs are restricted to specific operating costs, all parameters were found to be significant except the dummy variable for the purse seiners and the stock effect for four vessel groups.

Effect of output on unit costs in the herring fisheries

In the herring fisheries, output (Y) is a significant variable in explaining variable unit costs for all vessel groups, although the parameter is low for the purse seiners. Table 2 shows that the parameters have negative signs for all vessel groups, which indicate that the unit variable costs fall in output.

The negative sign might be caused by the inclusion of the quasi-fixed costs. Table 3 shows the results of regressions where the quasi-fixed costs and labour costs were kept out of the analysis, and the dependent variable is fuel and lubrication oil only. As shown in Table 3, the sign of the parameter did not change and the absolute value of $\overset{*}{\beta_1}$ increased to a significantly higher level for all vessel groups, indicating an even stronger relationship between catch and fuel costs per unit than between catch and the sum of operating/quasi-fixed costs.

As mentioned in section 2, set-up costs in the fishery may lead variable unit costs in the fishery to decrease in output if the number of trips necessary to produce the IVQ increases at a slower rate than an increase in the IVQ. Such a relationship effectively means that trip duration is longer at high IVQ than at low IVQ. Specific knowledge of the fishery indicates that this may have been a characteristic feature for two of the vessel groups fishing herring.

The catches of herring are sold either to plants that process the fish for the consumer market or to plants that produce fish meal and oil. The quality of the fish is much more important in the market for human consumption than in the market for fish meal and oil. For many of the vessels in the coastal and the pelagic trawler fleet, which are not equipped with modern storage facilities, quality can be improved by limiting the catch per fishing trip. During the early 1990s, when the TAC for the stock was at a low level, fishermen were only allowed to deliver their catch for human consumption, whereas when the TAC increased, this regulation was abandoned. The unit costs falling in catches may therefore be caused by a general shift from trips with low catches destined for human consumption at low quota levels to trips destined for industrial purposes at high quota levels.

The latter provides some explanation for why the unit costs are falling in output for the coastal vessels and the pelagic trawlers. The purse seiners have all had modern storage possibilities and delivered almost all of their catches to the market for human consumption throughout the period (1990-2000). Although the unit costs are falling in output for this vessel group as well, the parameter indicates that this takes place to a much lower degree.

Effect of output on unit costs in the cod fisheries

As in the herring fisheries, unit costs are falling in output in the cod fisheries. For four fleet segments, the parameter has a value between –0.22 and –0.28, whereas it is even higher for the coastal vessels with an overall length below 21 metres, see Table 2. Why should the unit costs fall more in output for these rather small vessels than for the others?

One reason might be the inclusion of quasi-fixed costs. For this reason, regressions where the dependent variable only consisted of fuel, ice and bait were performed. The same results were obtained as in the herring fisheries; the sign of the parameter did not change and the parameter value grew when quasi-fixed costs and labour costs were excluded, see Table 3. For the two groups of trawlers, and the coastal vessels with length between 21-28 metres, the parameter was significantly higher than in Table 2.

Again, will the number of trips in the cod fishery increase at a slower rate than an increase in the IVQs? With the exception of the factory trawlers, there are no specific reasons why this should be the case for a fleet that by and large delivers fresh fish to processing plants. Motivated by cost minimisation, the duration of the trips should be independent of the size of the IVQ[7].

[7] If the catch per unit effort decreased, this could of course motivate longer trips, but such an effect should then be caused by the fish stock and not the output or IVQ level.

A third explanation might be sought in incentives that arise under an output regulated fishery. When a quota regulates a vessel's output, the operator of the vessel will have an incentive to minimise costs. However, the price of cod depends on the individual size of the fish caught, so even under an output regulation, the operator of the vessel will have an incentive to catch as high a share as possible of large fish, and hence an incentive to discard the smaller fish (high-grading) exists.

High grading implies, however, that more effort is needed to reach a specific output level. Variable cost per unit (non-discarded) catch will then increase. For the vessel owner, these two contradicting incentives for profit maximisation will imply a trade off between incentives to discard low value fish on the one hand, and to minimise costs, on the other hand. As the quota increases, more effort will be needed to catch the quota. The trade-off between the incentives to high grade and minimise costs will then shift, and the operator's incentives to minimise costs will increase. Alternatively, when the quota tightens, the trade-off will move in the direction of stronger incentives to discard low value fish. Taking account of the remuneration system in the fisheries, where the payment to the crew is based on a share of the value of the output, the incentive to discard low value fish at low output levels should be even greater. Once hired on a fishing vessel, the real opportunity cost of one's own labour may be very low. The fishermen will then have an incentive to maximise the revenue, implying an even stronger incentive for high grading. All this implies that the number of trips may increase at a slower rate than an increase in IVQ, causing both unit variable costs to be decreasing in output.

Effect of biomass on unit costs in the herring fisheries

As mentioned, herring is a pelagic stock forming schools. A common assumption in the literature is that variable unit costs in fisheries targeting schooling species are independent of stock size. However, if vessels spend more time searching for schools of herring at low than at high stock levels, a stock effect may be found (Bjørndal, 1988).

For the pelagic trawlers, our results confirm an assumption of no stock effect, whereas a stock effect is found for the coastal vessels and the purse seiners (see Table 2). When the variable costs are restricted to fuel, Table 3 shows that an assumption of no stock effect is also confirmed for the purse seiners. This indicates that quasi-fixed costs may have caused the stock effect found for the purse seiners in Table 2.

However, the stock effect prevails for the coastal vessels irrespective of whether variable unit costs are covering operating and quasi-fixed costs or only the cost of fuel and lubrication. A much lower geographical range of operation than the two other vessel groups may cause this. As the name indicates, the coastal vessels operate along the Norwegian coast and it might be the case that a more abundant stock implies more schools of herring entering the waters where the coastal vessels operate, thus reducing these vessels' time spent searching for schools of herring.

Effect of biomass on unit costs in the cod fisheries

When variable costs are set equal to the sum of operating and quasi-fixed costs, a stock effect is found for all vessel groups. The data indicate that unit variable costs are decreasing in biomass. The parameter is estimated to –0.21 for the coastal vessel groups and –0.18 for the long liners, whereas it is substantially larger (in absolute terms) for the trawlers. Since the coastal vessels are using passive and trawlers active gear, one would assume that the stock effect should be higher for the coastal vessels than for the trawlers, but the opposite is found, see Table 2.

It should, however, be kept in mind that X represents spawning stock biomass in the regressions for the coastal vessels, whereas X represents total stock biomass in the regressions for the trawlers. The spawning stock biomass has a seasonal migration pattern where a characteristic feature is that the fish concentrate along the coastline of Northern Norway each spring. This gives rise to a coastal fishery on the spawning cod (the Lofoten fishery), which represents a fishery on a very dense concentration of fish. The total stock does not have this migration pattern, and may therefore be harder to locate for the trawlers at low total stock levels.

For the two groups of trawlers, the stock effects are estimated to –0.50 and –0.59, both significantly lower than 1, as implicitly assumed in the Schaefer model. This reflects that when biomass increases by 10%, variable unit costs decrease by 5 and 5.9% for the two vessel groups. If the cost per unit of effort is constant, this implies a stock-output elasticity of 0.5 to 0.59, which is higher than what Eide *et al* (2003) found (but not significantly so) when estimating harvest functions for 18 Norwegian trawlers harvesting the same species (0.42).

When quasi-fixed costs and labour costs were kept out of the regression, the stock effect is no longer significant for the coastal vessels between 21 and 28 metres. The stock effect is reduced for the coastal vessels below 21 metres and the two groups of trawlers, whereas it increases (in absolute terms) for the long liners.

It is, however, of interest to note that the stock elasticities for all five vessel groups are significantly lower than 1. This implies that when biomass increases, variable unit costs decrease less than proportional to the biomass. The parameters estimated cannot then support the general implication of the Schaefer function: that catch per unit effort should be proportional to the stock size.

Comparison of results for the cod and herring fishery

Cod and herring are two species that differ in many aspects. In relation to a fishery, the most important difference is that cod is a high-priced demersal non-schooling species, while herring is a lower-priced pelagic schooling species. Thus, they are targeted with different gear.

In the herring fishery, the results indicate that variable unit costs are decreasing in output, i.e. the output elasticity is negative. The output elasticities for the coastal vessels and purse seiners were found to be higher, and for the pelagic trawlers lower, than those estimated by Bjørndal and Gordon (2002), but the differences were not found to be significant. A negative output elasticity is also found in the demersal fishery for cod. This may be caused by the same factor as described for the herring fishery, but another explanation is an inverse relation between the levels of high grading and IVQ.

Furthermore, apart from one vessel group, the empirical analysis shows that pure operating unit costs are not responsive to biomass for the schooling species of Norwegian spring spawning herring, i.e. the stock elasticity is not significantly different from zero. These results confirm the results of Bjørndal (1987 and 1988). As expected, a stock elasticity different from zero was found in the demersal fishery for cod, but interestingly, at a significantly lower level than one. For the trawlers, the stock elasticity was found to be higher than what was found in Eide *et al* (2003) (but not significant so). For the coastal fleet and the long-liners, the stock elasticity was generally lower than what was found in Hannesson (1979).

The results indicate that variable unit costs in both fisheries are decreasing in output and that the elasticity of costs with respect to biomass is more similar than often assumed in the literature.

6 Concluding remarks

In this paper, the effect of biomass and output on unit variable harvesting costs is estimated on the basis of panel data. The data come close to two stylised fisheries often encountered in the literature, namely a pelagic fishery where unit costs are assumed independent of biomass and a demersal fishery where unit costs are assumed to be inversely proportional to biomass. Within the pelagic fishery, three vessel groups and within the demersal fisheries five vessel groups are analysed. Data are drawn from an 11-year period, during which both output and biomass in the two fisheries have changed considerably. It is found that variable unit cost decrease in output for both fisheries. It is further found that variable unit costs in the cod fishery are decreasing in biomass, but at a rate significantly lower than one. In the herring fishery variable unit costs are decreasing in biomass for one vessel group.

The method applied in this paper specifically addresses both output and biomass as explanatory variables for variable unit costs. This was also done by Weninger (1998), but it is not common in the fisheries economic literature, where one of the two is often analysed. In papers where cost function in the fishery is estimated, an example of which is Bjørndal and Gordon (2002), biomass is assumed constant and variable costs in the fishery are assumed to depend on output, capital and input prices. In papers dealing with harvest rules such as Hannesson (1979) and Bjørndal (1987 and 1988), the cost of a unit effort is assumed to be independent of output, and possible changes in unit costs are assumed to be caused by the fish stock.

As mentioned in the introduction, empirical evaluation of unit variable costs is important when choosing the optimal harvest rule, or target escapement (TE). The target escapement level will generally increase in stock elasticity. If variable unit costs decrease as the stock increases, this will, *ceteris paribus*, tend to increase the TE level relative to the TE level for fisheries where unit costs are constant in stock. Furthermore, if variable unit costs decrease as output increases this will, *ceteris paribus*, tend to move the TE towards the level characterised by maximum sustainable yield (MSY) relative to the TE level for fisheries where unit costs are constant in output. Whether the TE level for the two fisheries analysed here would have been moved when introducing the output and stock elasticities found in this paper will depend upon the biological growth model, as well as to the degree to which prices of the harvest will decrease in harvest.

Both output and stock elasticity differ between vessel groups. This implies that what might be considered the optimal TE level could also differ between vessel groups. In the herring fishery, the differences between output and stock elasticity for the coastal vessels, on the one hand, and the purse seiners, on the other hand, could imply different TE levels. Again, this must be established empirically by the use of a bioeconomic model, which is beyond the scope of this paper.

The negative output elasticities found in the cod fisheries raise several concerns. If these reflect high grading at low IVQ levels, managers should be concerned about the implementation success of IVQs when TACs decline. One policy implication is that monitoring and control should be increased when IVQ declines. Another policy implication would be to reduce the number of vessels allowed to participate in a fishery to keep IVQs stable when TACs are reduced.

The relatively low stock elasticity in the cod fisheries is also cause for concern. Departing from an assumption of stock elasticity at around 1, it has often been assumed that the fishery does not threaten demersal fish stocks. The reasoning is well known: as stocks decline, catch per unit effort decreases and variable costs per unit catch increase up to a point when fishing is no longer profitable, at which level fishing cease and the stock can rebuild. The low stock elasticity found in this paper indicates that variable unit costs are only moderately sensitive to stock size, which in turn indicates that a fishery will be profitable at far lower stock levels than at stock elasticities around 1.

In addition to their relevance for the question of optimal harvest rule, the results in this paper shed light on the economics in a fishery on a declining fish stock. The combined effect of a low stock elasticity and a negative output elasticity on a declining stock indicates that the operating profit of the fishery will be positive at lower stock levels than otherwise assumed, and that this profitability could be augmented by high-grading. This corresponds to what Myers *et al* (1997) anticipated as the driving forces in the collapse of 6 Atlantic cod stocks off the coast of Canada.

The results found in this paper thus reflect how variable unit costs in a Norwegian cod and herring fishery vary in response to changes in output and biomass, and may be indicative for how such costs vary in similar fisheries.

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Appendix A Description of vessel groups

In this appendix, a short description of the various vessel groups and some indicators are given. The abbreviation NSSH represents Norwegian Spring Spawning Herring, whereas the abbreviation NEA represents Northeast Arctic.

A1. Coastal vessels fishing Norwegian spring spawning herring

The coastal vessels are the smallest vessels with an overall length below 27.5 metres. These vessels target both demersal species, such as cod and haddock, as well as pelagic species such as saithe, herring and mackerel. The vessels generally operate close to the Norwegian shore. When fishing on pelagic species like herring and capelin, the vessel uses purse seine technology, while nets, hooks and long line are used when fishing on demersal species like cod and haddock.

Tqble A1 Some physical characteristics of the 281 coastal vessels

Parameter	Minimum	Mean	Maximum
Gross tonnage	49	176	377
Length overall (metres)	13	20	27
Age (years)	0	21	111
Days at sea	62	274	357
Catch of NSSH (tonnes)	50	622	2,805
Total catch (tonnes)	85	1,151	4,184

A2 Purse seiners fishing Norwegian spring spawning herring

The purse seiners are by far the largest vessels, with the most modern fishery equipment. They primarily fish pelagic species using purse seine technology, but in the fishery for Blue Whiting, the vessels shift technology to pelagic trawl. The purse seiners target a wide range of pelagic species, including mackerel, herring, capelin, horse mackerel, blue whiting and sprat. Their area of operation covers the Barents Sea in the north, the North Sea in the south and the areas west of the British Isles, as well as Icelandic waters in the northwest.

Table A2 Some physical characteristics of the 129 purse seiners

Parameter	Minimum	Mean	Maximum
Gross tonnage	231	453	2,574
Length overall (metres)	27	55	76
Age (years)	0	27	91
Days at sea	5	284	360
Catch of NSSH (tonnes)	95	2,677	7,632
Total catch (tonnes)	1,735	11,500	35,000

A3 Purse seiners fishing Norwegian spring spawning herring

The pelagic trawlers are generally smaller in size than the purse seiners. Their main fishery targets sandeel, blue whiting and Norway pout. In addition to this, they fish herring, mackerel and capelin. Their area of operation is mostly the North Sea, but capelin and herring are caught along the Norwegian coast. In all fisheries they use trawl technology.

Table A3 *Some physical characteristics of the 84 pelagic trawlers*

Parameter	Minimum	Mean	Maximum
Gross tonnage	96	295	599
Length overall (metres)	15	33	44
Age (years)	0	29	51
Days at sea	174	311	362
Catch of NSSH (tonnes)	12	755	1,709
Total catch (tonnes)	134	5,697	18,000

A.4 Coastal vessels 13-20.9 metres (passive gears)

This vessel group mainly targets cod, saithe and haddock. The vessels use nets, lines, Danish seine and hooks to gather their catch. According to the mean catch figures shown in Table A4, cod is definitely the most important species, and one would expect availability (stock size) and catch of cod to be important explanatory variables for the cost in the fishery.

Tqble A4 *Some physical characteristics of the coastal vessels with length 13 – 20.9 m.*

Parameter	Minimum	Mean	Maximum
Gross tonnage	11	30	137
Length overall (m)	13	16	21
Age	0	23	90
Days at sea	154	272	364
Catch of NEA Cod (tonnes)	0	111	763
Catch of NEA Haddock (“)	3	23	266
Catch of NEA Saithe (“)	6	64	591
Total catch (tonnes)	2	260	1,460

A.5 Coastal vessels 21-27.9 metres (passive gears)

Table A5 shows some physical properties of coastal vessels larger than the ones shown in Table A4. They also catch a substantial amount of cod, saithe and haddock, but in addition to this, their total catch indicates large catches of other species. This largely constitutes herring and capelin, which these vessels catch in specific seasons with alternative gear (purse seine). As for the vessels of lengths between 13 and 21 metres, one would expect availability and catch of cod to be important factors for the cost of catching cod.

Table A5 *Some physical characteristics of coastal vessels with length 21 – 27.9 m.*

Parameter	Minimum	Mean	Maximum
Gross tonnage	49	113	264
Length overall (m)	21	24	28
Age	1	22	59
Days at sea	62	272	364
Catch of NEA Cod (tonnes)	41	238	953
Catch of NEA Haddock (“)	14	38	244
Catch of NEA Saithe (“)	4	105	595
Total catch (tonnes)	148	897	2,789

A.6 Long-liners above 28 metres (passive gears)

The long liners fish mainly off the coast, and in addition to cod and haddock, they fish large quantities of tusk, ling, ocean catfish, saithe and Greenland halibut. Of the latter, large quantities of ling, tusk, Greenland halibut and saithe are caught in areas other than those where NEA cod is distributed.

Table A6 Some physical characteristics of coastal vessels with length above 28 m.

Parameter	Minimum	Mean	Maximum
Gross tonnage	100	216	688
Length overall (m)	28	37	51
Age	0	17	42
Days at sea	207	311	356
Catch of NEA Cod (tonnes)	11	306	874
Catch of NEA Haddock (“)	0	119	947
Catch of NEA Saithe (“)	0	58	439
Total catch (tonnes)	170	1,273	3,398

As can be seen from Table A6, the average catch of NEA cod, haddock and saithe constitutes less than 40% of the total catch, and saithe alone less than 5%. A large part of the remaining 60% of the catch is either caught in other areas than where NEA cod occurs or in other targeted fisheries.

A.7 Fresh fish trawlers (vessels catching and delivering fresh fish)

The fresh fish trawlers’ catch of NEA cod, haddock and saithe constitutes nearly ¾ of their total catch on the average. In addition to this, the catch consists of shrimp, redfish and also saithe in the North Sea.

Table A7 Some physical characteristics of fresh fish trawlers (vessels catching and delivering fresh fish)

Parameter	Minimum	Mean	Maximum
Gross tonnage	33	280	499
Length overall (m)	18	41	54
Age	0	19	51
Days at sea	112	286	364
Catch of NEA Cod (tonnes)	3	723	2,882
Catch of NEA Haddock (“)	2	206	1,168
Catch of NEA Saithe (“)	1	626	3,607
Total catch (tonnes)	50	2,149	5,335

A.8 Factory trawlers (vessels with onboard processing facilities)

The fifth Norwegian vessel group catching NEA cod is the factory trawlers. As the name indicates, the fleet process the catch. In addition to NEA cod, haddock and saithe, these vessels target shrimp, saithe in the North Sea and redfish in other areas.

Table A8 *Some physical characteristics of factory trawlers (vessels with onboard processing facilities)*

Parameter	Minimum	Mean	Maximum
Gross tonnage	473	777	1,428
Length overall (m)	49	61	76
Age	1	9	30
Days at sea	163	312	365
Catch of NEA Cod (tonnes)	150	1,383	4,495
Catch of NEA Haddock (“)	2	419	1,439
Catch of NEA Saithe (“)	7	842	2,636
Total catch (tonnes)	511	4,701	8,107

Appendix B Tables showing data on costs, catch and biomass

Table B1. Cost items collected by the Norwegian Directorate of Fisheries and classification into fixed, quasi-fixed or operating costs used in this paper.

No	Item	Classification
R.01	Operating revenues	-
R.02	Fuel and lubrication oil	Operating
R.03	Special social fees	Operating
R.04	Bait, ice, salt and packing	Operating
R.05	Social expenses	Operating
R.06	Insurance of vessel	Quasi-fixed
R.07	Other insurance	Quasi-fixed
R.08	Maintenance of vessel	Quasi-fixed
R.09	Maintenance/investment in gear	Quasi-fixed
R.10	Unspecified expenses	Operating
R.11	Food	Operating
R.12	Wages/share to crew	Operating
R.13	Estimated depreciation	Fixed
R.14.	Total operating expenses	-
R.15	Operating profit	-
R.16		
R.17	Financial income	-
R.18	Profit on exchange	-
R.19	Total financial revenue	-
R.20	Financial costs	Fixed
R.21	Loss on exchange	-
R.22	Total financial expenses	-
R.23	Net financial items	-
R.24	Profit on ordinary act before tax	-

Table B2 *Average unit variable costs (operating and quasi-fixed costs) for the three vessel groups fishing Norwegian spring spawning herring. NOK per tonne.*

Year	Coastal vessels	Purse Seiners	Pelagic trawlers
1990	3833	2458	1973
1991	3323	1487	2821
1992	2730	1854	2317
1993	1715	1866	1994
1994	1472	1686	728
1995	1411	1254	785
1996	1634	1198	635
1997	1778	1338	1675
1998	1257	1263	842
1999	1282	1266	968
2000	1311	1248	1173

Table B3 *Average unit variable costs (operating and quasi-fixed costs) for the five vessel groups fishing Northeast Arctic cod. NOK per tonne.*

Year	Coastal, 13-21	Coastal, 21-28	Long liners	Fresh fish trawl	Factory trawl
1990	19366	9985	10854	9098	12121
1991	15369	5925	13639	9030	8303
1992	8620	6414	9049	6242	7689
1993	9145	6542	8338	4499	7232
1994	7553	5926	8682	4295	5753
1995	7836	6410	8285	4284	5189
1996	6757	6222	8518	4455	6558
1997	5835	4862	7574	5292	7591
1998	8527	6280	9173	6390	9010
1999	9150	7290	9364	6731	10106
2000	9769	9425	9544	7476	14145

Table B4 *Annual average vessel output of herring during the period 1990 – 2000. In tonnes.*

Year	Coastal vessels	Purse seiners	Pelagic trawlers
1990	141	232	96
1991	139	200	97
1992	210	293	114
1993	296	941	230
1994	599	1783	505
1995	574	2827	671
1996	701	3678	896
1997	705	4713	985
1998	1030	4222	1012
1999	1162	4179	1081
2000	1178	4039	1124

Table B5 Annual average vessel output of cod during the period 1990 – 2000. In tonnes.

Year	Coastal, 13-21	Coastal, 21-28	Long liners	Fresh fish trawl	Factory trawl
1990	43	77	132	267	401
1991	53	114	145	206	391
1992	76	157	181	536	874
1993	90	178	255	631	1294
1994	126	242	353	1040	2179
1995	131	329	517	906	1774
1996	151	314	409	856	1657
1997	197	415	475	1185	1887
1998	148	289	340	723	1664
1999	101	215	362	639	1219
2000	74	165	345	500	1181

Table B6 SSB of Norwegian spring spawning herring and TSB/SSB of Northeast arctic cod. In tonnes.

Year	Norwegian spring spawning herring	Northeast Arctic cod	
	SSB	TSB	SSB
1990	2 957 154	963 046	343 489
1991	3 047 216	1 558 196	641 481
1992	4 187 096	1 899 457	892 648
1993	4 300 433	2 291 839	746 595
1994	4 956 846	2 017 694	606 245
1995	5 495 927	1 680 824	500 529
1996	5 268 201	1 609 946	579 385
1997	4 821 384	1 467 101	564 704
1998	4 232 596	1 151 504	388 456
1999	4 775 057	1 075 642	251 988
2000	4 828 711	1 084 258	222 138

Appendix C Allocation of costs to specific fisheries

The data are given annually for a panel of vessels, and they describe the income and cost for each vessel during a year. From these data, variable unit costs across fisheries (averages over the sum of fisheries) can be calculated.

Since the effort used to catch a unit of fish may differ between fisheries, there is no guarantee that the average unit costs across fisheries are identical to the unit cost in one of the fisheries in which the vessel operates. A hypothetical example will illustrate this:

Consider a vessel that during a year operates in two fisheries. These are a mixed fishery for cod, haddock and saithe, on the one hand, and the fishery for herring on the other. If this vessel during a year reports variable costs of NOK 1 million and has caught 100 tonnes of cod, haddock and saithe and 100 tonnes of herring, the average cost per tonne will be NOK 5.000.

Suppose the vessel had operated for 8 months in the mixed cod fishery and 2 months in the herring fishery. Since the cost of operating the vessel mostly depends on time spent fishing, the cost of operating the vessel for a month could be set to NOK 100,000. This implies that the cost in the mixed cod fishery will be NOK 800,000 and the cost in the herring fishery 200,000 NOK. Thus, with the information on time spent in the respective fisheries, the unit costs in the mixed cod fishery would have been NOK 8.000/tonne and in the herring fishery NOK 2.000/tonne.

This example illustrates that to find the unit cost in a specific fishery, it is necessary to know how much effort is expended in each fishery. In the absence of such specified data there is a need for an approximation of how effort is allocated. The approximation used in this paper is based on two steps. First, the number of fishing days for each vessel is allocated evenly across the number of months in which the vessel has shown activity, as registered by sales notes. Second, within each month the number of fishing days is allocated to the respective fisheries in accordance with the catch weight in the respective month.

The number of fishing days spent in the relevant fishery can then be approximated as follows:

$$A = \sum_{j=1}^{M_a} \left(\frac{B}{M_a} * \frac{Y_j}{C_J} \right) \quad \text{(A1)}$$

where

A : Days utilised by the vessel in the relevant fishery
B : Total number of fishing days per year
M_a : Number of “active” months for the vessel in the respective year
Y_j : Quantity of relevant fishery delivered in month j
C_j : Total quantity delivered in month j

This approximation to the number of fishing days in a specific fishery may be biased for two reasons. First, distributing the number of fishing days evenly on the “active months” of the vessel may be incorrect. There may be some “active months” with more fishing days than others. Second, allocating the number of fishing days within each month to the respective fisheries on the basis of catch may be subject to the same kind of error as illustrated in the example above (where this allocation key is used on a yearly basis).

Experiments with the data indicate that these two sources of error are not important in the herring fishery. This statement is based on two observations: First, the approximation gives an allocation of fishing days very close to an independent interview survey conducted by the Norwegian Directorate of Fisheries (1990 – 1996). Second, changing the criteria (Y_j) from quantity to value did not change the average number of fishing days allocated to the various fisheries by more than 4-5%.

The reason why the approximation seems to be good can be found in the seasonality of the fisheries. Once engaged in a fishery, a vessel generally continues to operate in this fishery for periods longer than a month. This implies that, for some months, the fishery of interest is the only fishery conducted, while in other months the vessel will not have been active in the fishery at all. Once fishing days have been assigned to the respective months, the monthly allocation key utilises this feature in the fishery to sort out which fishery a vessel is engaged in, and allocates effort (fishing days) accordingly.