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**Output Regulation of Multiproduct Firms:
An application of the Quadratic Profit Function**

by

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Output Regulation of Multiproduct Firms: An application of the Quadratic Profit Function¹

Abstract. The paper employs the symmetric normalised quadratic (SNQ) profit function presented by Kohli (1993) to estimate for interaction effects between restricted and unrestricted outputs in firm production. Based on data for individual firms, the profit function is employed for revealing the spillover effects between regulated and unregulated outputs, the elasticities of intensity, and firms' willingness to pay for additional production quota in a quota regulated industry. The result indicates that external effects prevail, which means that in the case of quota shortage firms will substitute towards increased harvesting of unregulated outputs, this action however increases the production costs for the average firm.

JEL classification: D23, Q21, Q22

Keywords: Multi-Output Fisheries, Quota Restrictions, Production Structure

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I. Introduction

Output regulation is one of the key instruments for preventing overexploitation of fish resources. The individual transferable quota (ITQ) is among the management tools most often recommended by economists as an essential element for obtaining sustainable fishery management. Empirical studies indicate that fish resources are harvested by multiproduct firms that are harvesting several outputs in a joint production (Jensen, 2002). Imposing ITQ on an individual species might therefore have external impacts on other species not intended for by regulation. This paper addresses spillover effects between regulated and unregulated species using the dual approach, based on information of the profit function for the multiproduct harvesting firms.

Squires (1987ab), Squires and Kirkley (1991) use the dual approach for revealing jointness in production of outputs that are not binding by ITQ quota regulation. The management by ITQ means that firms cannot freely decide on the quantity to harvest, instead the harvest quantity is predetermined by regulation, i.e., quota is an exogenous factor in the multioutput production function for the firm. One consequence of the ITQ regulation is that the firms might consider to increase the harvest of unrestricted outputs and thereby compensating for a tightening quota. Alternatively, the firm might respond to a tightening quota by decreasing the overall production activity, for example by reducing the number of active fishing days at sea. These conditions are exploited carefully in an application on the Norwegian purse seine industry. Moreover the multioutput cost structure, and the willingness to pay for additional quota for the firms is revealed that is conditions, which have relevance for management of the industry. Dual applications are building one of two assumptions. Firstly, Squires (1987ab), Squires and Kirkley (1991) are assuming that none of the outputs are imposed by regulation that restricts output supply. Lipton and Strand (1992), Weninger (1998), Bjørndal and Gordon (2002) are assuming that all outputs in the production are restricted. The contribution of this paper is that we use the dual approach to analyse a production of both restricted and unrestricted outputs, and addresses the external effects prevailing in the production.

The paper is organised as follows. The production and regulation circumstances for the purse seine firms are outlined in the following section. The empirical model and theoretical results obtainable for the industry is presented in section III. The description of data, estimation, and empirical results are presented in section IV and V. A summary with the findings and perspectives for public management of the industry is outlined in the final and concluding section.

II. The fish harvesting of the Norwegian purse seine fleet

Before we go into the theoretical modelling of the industry, we are presenting the background of production and regulation for the purse seine firms. In Norway, the purse seine vessels have homeports from Finnmark in the North to Rogaland in the South that is a distance of about 2000 kilometres. The purse seine gear is specialised for harvesting pelagic species that appear in shoals (herring, mackerel, capelin, sandell), whereas the gear is rather inefficient for harvesting demersale species (cod, haddock, saithe, sole, and etc.). The purse seine vessels flexibility for altering fishery tactics between pelagic and demersale species is rather limited, as opposed to for example trawlers. The public management of fish resources acknowledges the efficiency of the purse seines in the pelagic fishery by allowing these vessels individual vessels quota (IVQ). The IVQ management is employed for mackerel, herring in the North Atlantic (spring spawning herring) and the North Sea, and capelin in the Barents Sea and at Jan Mayen. The IVQ is distributed gratis to the purse seine vessels on an annual basis. The individual quotas are not transferable between the vessels during the season, but in the case the total annual quotas for the fishery are not completely exploited, the vessels have the possibility to apply for an additional quota (Asche, Bjørndal, Gordon, 1998). The flexibility of travelling is an important feature of the purse seiners, because their IVQs are distributed in the different fishing areas from the Barents Sea in the North to the North Sea in the South. Fisheries of capelin in the Barents Sea is regulated to take place between 15 January and 15 April in the Barents Sea and June/July at Jan Mayen, large fluctuations appear in the stock meaning that is not usually that the capelin fishery is closed. The spring spawning herring is located along the Norwegian coast between October and February/Mars, and between Mars and October the spring spawning herring moves to the Norwegian Sea in the search for feed. Seasonal regulation on the spring spawning herring is not imposed. The purse seiners attempt to harvest spring spawning herring when it is located along the Norwegian coast, because it has a high quality during the period. The mackerel is harvested along the West Coast of Norway and in the North Sea. Seasonal regulation is not imposed on the mackerel fishery, but the fishery mainly takes place between September and November. The harvesting of North Sea herring takes place during the spring and the autumn.²

² Communication with Per Sandberg, the Norwegian Directorate of Fisheries is acknowledged.

III. Empirical model

Profit function restricted in quoted output

Production quotas are often used for managing fish resources that are vulnerable to overexploitation. The uses of individual vessel quotas are featuring quotas assigned to individual vessels. Bjørndal and Gordon (2000), Weninger (1998) applies cost functions for describing the behaviour of vessels that are regulated by individual vessel quotas. The cost function approach builds on the assumption that the vessels are minimising cost in the production of the quoted outputs. The argument for cost minimisation of outputs seems reasonable for all outputs, which are predetermined by quotas on an individual vessel basis.³ However, if the firms are harvesting outputs that are not restricted by quotas, these outputs are not predetermined. Instead it is reasonable to assume that the firms are producing these unrestricted outputs under assumption of profit maximisation, and supply functions for these variable outputs are applicable. We apply the restricted profit function containing both restricted and unrestricted outputs for analysing the Norwegian purse seine vessels.

The Symmetric Normalised Quadratic (SNQ) profit function introduced by Kohli (1993) is employed. The advantage of this functional form is twofold. Firstly, the SNQ function builds on an index of the variable prices for normalisation, and thereby avoiding to scrip one of the variable prices for normalisation, which is accommodated by using for example the translog function form. Diewert and Wales (1987) emphasise that estimated results depend critically on which variable is used for normalisation; this is not an issue when using the SNQ, because all variable prices are used. Secondly, the quadratic profit function is operational even when the profit is negative, which is an important feature when applying the profit function for describing a production process with many restricted outputs. The profit π is defined as the landing value of the unrestricted outputs minus cost of variable inputs. The restricted quadratic profit function is defined as,

$$1) \quad \pi = \sum_i^2 \alpha_i P_i + \frac{1}{2} \sum_i^2 \sum_j^2 \alpha_{ij} P_i P_j / \sum_i^2 (\theta_i P_i) \\ + \frac{1}{2} \sum_k^3 \sum_j^3 \rho_{kj} Y_k Y_j (\sum_i^2 \theta_i P_i) + \frac{1}{2} \beta_i ZZ (\sum_i^2 \theta_i P_i)$$

$$+ \sum_i^2 \sum_k^3 \gamma_{ik} P_i Y_k + \sum_i^2 v_i P_i Z + \sum_k^3 \phi_{ik} Y_k Z (\sum_i^2 \theta_i P_i),$$

where

π is the restricted profit (total landings – variable costs),

P_i is positive for output prices and input prices, ($i = o, f$, where o is output, and f is fishing days)

$\sum_i^2 \theta_i P_i$ is the summarised price index,

θ_i is the weight of the i th variable item in the price index,

q_i are the quantities of the variable input and output, ($i = o, f - o$, where o is output, and f is fishing days)

Z is the level of the quasi-fixed input (TE)

Y_k are the quantity of restricted outputs ($k = h, c, \text{ and } m$, where h is spring spawning herring, c is capelin and m is mackerel and North Sea herring)

In the profit function, the quantities of inputs are assigned negative values; quantities for output, and prices on inputs and outputs are all assigned positive values. Using Hotelling's and Shephard's lemmas one derives functions for variable output supply and input demand as,

$$2) \frac{d\pi}{dp_i} = q_i = \alpha_i + \sum_i^2 \alpha_{ij} P_j / (\sum_i^2 \theta_i P_i) - 1/2 \sum_i^2 \sum_j^2 \alpha_{ij} \theta_i P_i P_j / (\sum_i^2 \theta_i P_i)$$

$$+ 1/2 \sum_k^3 \sum_j^3 \rho_{kj} (\theta_i) Y_k Y_j + 1/2 \beta_i (\theta_i) Z Z$$

$$+ \sum_k^3 \gamma_{kj} Y_k + v_i Z + \sum_k^3 \phi_{ik} (\theta_i) Y_k Z.$$

From (2) it is noted that one may estimate all parameters of the profit function (1) by used of function of the variable components. This means that the empirical result is obtained either by estimating equation (1), equation (1) and (2), or equation (2) alone. Symmetry is imposed by requiring that $\alpha_{ij} = \alpha_{ji}$ and $\rho_{jk} = \rho_{kj}$. Linear homogeneity is imposed by the term $\sum_i^2 \theta_i P_i$, where θ_i are non-negative shares and P_i are the prices on the variables input and outputs.

³ Group quotas applied for a group of vessels will not necessarily result in that outputs are pre-determined for the vessel at the individual level.

Shadow values of the quoted outputs (marginal cost of restricted outputs)

The marginal cost of producing one additional unit of the restricted output is found by differentiating (1) with the restricted output (Y_k), and we obtain

$$3) d\pi/dY_k = (\sum_i^2 \theta_i P_i)(\sum_k^3 \rho_{kj} Y_k + \phi_i Z) + \sum_i^2 \gamma_{ik} P_i.$$

The shadow value that is the firms' willingness to pay for additional quota of the regulated output is found as $P_{yi} - d\pi/dY_k$ that is the difference of landing price and marginal production cost.

Elasticity of transformation, substitution and intensity

The own price elasticities of the variable input and output follow as,

$$4) (dq_i/q_i)/(dp_i/p_i) = \{ \alpha_{ii}/(\sum_i^2 \theta_i P_i) - \alpha_{ii} \theta_i P_i / (\sum_i^2 \theta_i P_i)^2 - \alpha_{ij} \theta_i P_j / (\sum_i^2 \theta_i P_i)^2 \\ - (\alpha_{ii} \theta_i P_i) / (\sum_i^2 \theta_i P_i)^2 + \alpha_{ii} \theta_i^3 P_i^3 / (\sum_i^2 \theta_i P_i)^4 \\ - (\alpha_{ij} \theta_i P_j) / (\sum_i^2 \theta_i P_i)^2 + \alpha_{ij} 2 \theta_i^3 P_i^2 P_j / (\sum_i^2 \theta_i P_i)^4 + \alpha_{ij} \theta_j^3 P_j^2 P_i \} p_i/q_i.$$

The cross price elasticity follows as,

$$5) (dq_i/q_i)/(dp_j/p_j) = \{ - \alpha_{ii} P_i \theta_j / (\sum_i^2 \theta_i P_i) + \alpha_{ij} / (\sum_i^2 \theta_i P_i) - \alpha_{ij} \theta_j P_j / (\sum_i^2 \theta_i P_i)^2 \\ + \alpha_{ii} \theta_i P_i^2 \theta_j^2 P_j / (\sum_i^2 \theta_i P_i)^4 - \alpha_{ij} \theta_i P_i / (\sum_i^2 \theta_i P_i)^2 \\ + \alpha_{ij} 2 \theta_j^2 P_j^2 \theta_i P_i / (\sum_i^2 \theta_i P_i)^4 - \alpha_{22} \theta_i P_j / (\theta_i P_i)^2 + \alpha_{22} P_j^3 \theta_i \theta_j^2 / (\sum_i^2 \theta_i P_i)^4 \} p_j/q_i$$

Elasticity of intensity measures the impact that the restriction has on the unrestricted components (Diewert, 1974). In the IVQ managed industry the elasticity of intensity is employed to measure the impact that the quoted output, Y_i , has on the variable components q_i (input or output). For the SNQ profit function we obtain,

$$(dq_i/dY_k)/(Y_k/q_i) = \gamma_i + \theta_i (\sum_k^3 \rho_{kj} Y_k + \phi_i Z) Y_k/q_i.$$

Multiproduct cost structure

Cost complementarity between restricted outputs is used as an indicator economics of scope, which we express as,

$$\delta(\delta\pi/\delta Y_k)/\delta Y_j = (\sum_i^2 \theta_i P_i) \rho_{kj}.$$

A negative sign indicate the presence of economics of scope and producing several output reduces the costs.^{4,5} In addition, cost complementarity in producing the regulated and unregulated outputs in a joint production can be found based on the derivative $\delta^2\pi/\delta Y_k \delta P_i$.

Product specific scale economics is uncovered by addressing the incremental marginal costs (IMC), $\delta\pi/\delta^2 Y_k$, negative IMC implies decreasing marginal and average cost and thereby increasing returns to scale. Constant returns to scale is indicated by $IMC = 0$ implying constant marginal and average cost, and $IMC > 0$ implies increasing marginal and incremental average costs and thereby indicating decreasing returns to scale (Baumol *et al.* 1982). For the quadratic function the IMC is stated as,

$$\delta(\delta\pi/\delta^2 Y_k) = \rho_{kk} (\sum_i^2 \theta_i P_i).$$

IV. Data and Estimation

The Norwegian Directorate of Fisheries supplied data of accounts and landings for the purse seiners covering the period 1992-1999. The profit function consists of the four outputs restricted by vessels quotas: spring spawning herring, North Sea herring, mackerel and capelin. In addition, the vessels are harvesting a range species (e.g. Atlantic horse mackerel, sandeel, sprat, cod, haddock, and etc.), which are not restricted by individual vessels quotas, therefore considered as variable outputs.⁶

⁴ Cost complementary for the variable outputs can be stated using the inverse to Hessian matrix to the profit function, (see Sakai 1974, and Lau 1976).

⁵ Cost complementarity between restricted and unrestricted output is defined by $\delta^2\pi/\delta y_k \delta p_i = \gamma_{ik}$.

⁶ In general the harvest of the demersale species like cod and haddock are of minor importance caught randomly by the purse seiners.

Table 1. *Mean characteristics for the purse seine vessels 1996*

Catch and Vessel characteristics	Mean	Minimum	Maximum	Variance
Fishing days	249	187	360	42
TE	644	290	1200	252
Catch spring spawning herring (kilo)	3467524	2384558	4275438	486973
Catch capelin (kilo)	1538399	0	3559847	1338987
Catch mackerel and NS herring (kilo)	1330155	906269	1706294	486973.5
Price spring spawning herring ¹⁾	1.91	1.50	2.39	0.21
Price capelin ¹⁾	0.32	0.57	0	0.24
Price mackerel and NS herring ¹⁾	6.49	5.47	8.04	0.63
Catch quantity of other species (kilo)	893316	0	5532414	1192472
Price on other species (per kilo) ¹⁾	1.88	0	9.06	2.35
Cost per fishing days (NOK) ²⁾	35573	21759	63173	8433

Source: The Norwegian Directorate of Fisheries.

1) The prices are in Norwegian kroner per kilo.

2) Cost per fishing days in Norwegian kroner and defined as all operating costs except cost for maintenance, imputed depreciation, and acquisition cost.

The number of operating fishing days is the variable input, the size of each vessel measured in hectolitre is a quasi-fixed input. The variable cost per fishing days is measured as the operating costs including crew remuneration, fuel consumption.⁷

The data consists of purse seiners operating in the period 1992-1999; the purse seine vessels participating in the blue whiting fishery are not included. The used of the aggregated index for normalising, $\sum_i^2 \theta_i P_i$, in the SNQ profit function is based on the prices of variable outputs and the unit cost of the variable input. Information of individual vessel's revenues of variable outputs and cost expenditures are used for defining the weights θ_i . The cost of the variable input per fishing days is constructed as the cost of remuneration, fuel, and etc., divided by the number of fishing days. As basis for constructing the index, the unit prices on output and unit cost on input the cost per fishing days are indexed compared to the base year 1996. This year is chose as base year because it contains the largest number of active vessels.

The variable outputs consist of a range of different species, and consistent aggregation of these outputs is accommodated. A Fisher quantity index is used following Coelli, Rao and

⁷ The cost per fishing days includes cost for fuel, salaries, insurance and other crew costs (costs for maintenance, acquisitions, and depreciation are not included).

Battese (1998).⁸ The base 1996 year is used for constructing the quantity index, which builds on all vessels that are active in fishery for at least two years, fishing activity of the vessels in 1996 is mandatory. The Fisher quantity index employed,

$$Q_{s,t} = [\sum p_{i,t} q_{i,t} / P_{s,t}] / \sum p_{i,s} q_{i,s}^*$$

where

$p_{i,t}$ is the average prices for the variable outputs for all vessels in the year from 1992 to 1999

$q_{i,s}^*$ is the average output quantities for each vessel in every year from 1992 to 1999

$p_{i,s}$ is the average prices for the variable outputs for all vessels in the base year 1996

$q_{i,s}^*$ is the average output quantities for each vessel in the base year 1996

The forming of the quantity index builds on the average annual prices taking into account differences in the composition of the species between the years, and differences in quality pressed in the price differences between the years. The construction of the quantity index reduces the initial number of observations from 270 to 170 observations. The price on the aggregated variable output is then found by dividing the revenue of the unrestricted outputs by Fisher output quantity index (Helming, Oskam and Thijssen, 1993).

The estimation of the profit function builds on the input demand of the fishing days and the output supply of variable outputs. The number of operating fishing days is only counting the days in active fishery in the field. Idle time of no fishing exists due to travelling time to the fishing fields, time in dock for repairing of the vessel, and absence due to bad weather conditions. In this sense the number of operating fishing days is partly explained as a result of different reasons for idle time. We have therefore constructed a proxy variable, A, which is defined as 365 days minus operating fishing days, taking into account idle fishing days. The regression on the absent days follows as,

$$5) A = \beta_0 + \beta_1 R + \beta_2 AGE + \sum_n^2 \beta_n D_R + \sum_m^2 \beta_m D_Y,$$

where A is idle days of no fishery operation, R is measuring the repair cost (deflated by the price index to 1996 price), Age denotes the age of the vessel, and D_R , D_Y are dummies for home region and year. The R-square=0.46 is found for the regression for idle fishing days.

⁸ The Fisher price index has the advantage that it can be used even when some observations are zero, this is not possible by using the Tornquist index building on the translog form.

The repair cost and regional and annual dummies are giving significant explaining the absent days, whereas the AGE component is not statistical significant.

In the estimation the system singularity problem is encountered. As indicated in table 2, the high correlation is found between mackerel and North Sea herring thereby creating multicollinearity problems in the estimations. The multicollinearity problem is resolved by aggregating mackerel and North Sea herring into a single restricted output. The aggregating of the mackerel and North Sea herring is undertaken as a Fisher quantity index mentioned above.

Table 2. *Spearman's correlation coefficient between IVQ quantities*

	SS herring ¹⁾	NS herring	Mackerel	Capelin
SS herring	1	-0.435*	-0.504*	-0.315*
NS herring	-0.435*	1	0.845*	-0.351*
Mackerel	-0.504*	0.845*	1	0.424*
Capelin	-0.315*	-0.351*	0.424*	1

* Correlation is significant at the 1% level (2-tailed).

1) SS stands for spring spawning, and NS stands for North Sea.

V. Estimation and empirical results

The variable functions for unrestricted output and number of operating fishing days from equation (2) are estimated by used of FIML until the presence of convergence (R-squares of equation 0.84 and 0.35). The parameter estimates are presented in table 3. For purpose of rescaling, each variable is centered on the mean of the variable in 1996.

Table 3. *Parameter estimates for purse seine vessels*

Parameter	Estimate	t-statistics	Parameter	Estimate	t-statistics
α_o	2.762588	8.750479	γ_{om}	-0.748849	-4.037837
α_f	-0.526726	-5.053565	γ_{oc}	-0.074218	-0.823387
α_{oo}	-0.022189	-0.838328	ν_o	0.145943	0.349802
α_{ff}	-0.172351	-5.297901	ϕ_{oh}	0.271515	1.132768
α_{of}	-0.387457	-3.263383	ϕ_{om}	-0.038894	-0.326577
ρ_{hh}	0.169651	0.788102	ϕ_{oc}	-0.021492	-0.335583
ρ_{hm}	-0.028832	-0.308534	κ_o	-1.066714	-3.477348
ρ_{hc}	-0.065044	-1.274264	κ_f	0.330047	4.405552
ρ_{mm}	0.190320	2.898323	γ_{fh}	-0.410231	-2.975331
ρ_{mc}	0.002102	0.069612	γ_{fm}	-0.322639	-4.036750
ρ_{cc}	0.047876	1.028397	γ_{fc}	-0.061835	-1.761483
β_1	0.065767	0.202766	ν_f	-0.188096	-0.969889
γ_{oh}	-0.648821	-2.260729			

For the purpose of addressing the external effects between species harvested two Wald tests on jointness in inputs are undertaken. The test results are presented in table 4. The hypothesis of jointness in inputs measures for external effects in producing several outputs. The first test investigates whether there is any spill over effects between the restricted outputs. The test statistic on the hypothesis $\rho_{hm} = \rho_{hc} = \rho_{cm} = 0$ indicates that we cannot reject hypothesis of nonjointness. This indicates that the harvesting of capelin, herring, mackerel can be modeled as separate production functions and there is no spillover effects between the fisheries. In terms of cost structure the result indicate that there is no interaction in the harvesting of the restricted outputs exists. Hall (1973) emphasises that technically the result means that the total cost for harvesting the regulated outputs is equal to the sum of harvesting cost of each of these outputs. In addition, the result has the management implication that the regulator applying individual quota has no spillover effects on the other restricted outputs.

Secondly, we are testing for nonjointness between restricted and unrestricted outputs. The test is accommodated by the hypothesis that $\gamma_{oh} = \gamma_{om} = \gamma_{oc} = 0$, and test result indicates that there jointness in the production of restricted and unrestricted outputs is present. In this sense the production of the unrestricted output cannot be seen independently of the production of the restricted outputs. In other words there is indication of external effects in the production of the

restriction outputs on the unrestricted outputs. In the following we are addressing further whether the restricted and unrestricted outputs are produced as complements or substitutes.

Table 4. *Hypothetical tests (Wald test)*

Null hypothesis	Test statistics	Critical value ($\alpha \leq 0.05$)	Degrees of Freedom	Conclusion
	Chi-square			
Non-jointness restricted outputs a)	1.636	7.815	3	Accept null (nonjointness)
Non-jointness restrict. & unrestrict. outputs b)	17.026	7.815	3	Reject null (jointness)

Note: a) Test on nonjointness in inputs between restricted outputs, $H_0: \rho_{hm} = \rho_{hc} = \rho_{cm} = 0$,
 b) Test of nonjointness in inputs between unrestricted output and restricted outputs, $H_0: \gamma_{oh} = \gamma_{om} = \gamma_{oc} = 0$.

The cost complementarity indicates the existing of decreasing cost in producing several outputs, which is a sufficient condition for economics of scope. In the first columns of table 5 we are presenting the results on cost complementarity in the production of several outputs. The cost complementarity between the restricted outputs in the first two columns indicates the presence of none cost complementarity (NCC) in the production of the regulated outputs. The result is not surprising, but is in accordance with the result of nonjointness in inputs found earlier, because for species produced is separate production processes no reasons are found for cost complementarity.

The measures of cost complementarity between the unrestricted output and restricted outputs indicate the presence of anti cost complementarity (ACC). This means that the vessels are obtaining increasing cost in the joint production of restricted and unrestricted outputs. Harvesting restricted and unrestricted outputs gives higher production cost. The situation might indicate that in years of high quotas on regulated species (except for capelin), the vessels will have lower costs, whereas low quotas push the vessels to increase their harvest of unrestricted output, which will increase their costs.

The result on product specific returns to scale indicate constant return to scale in the capelin fishery and spawning herring fishery.⁹ Decreasing returns to scale is found in the mackerel and North Sea herring fishery, the result denies the capability of large scale vessel for paying higher than average prices on IVQ for these species, if there were sold in auctioned markets.

Table 5. *Cost complementarity, single and multiproduct returns to scale*^{1,2}

<i>Cost complementary</i>				<i>Returns to scale</i>
SS herring	Capelin ³⁾	Mackerel and NS herring ³⁾	Unrestricted output ⁴⁾	Single product ⁵⁾
SS herring	NCC	NCC	ACC	CRTS
Capelin		NCC	NCC	CRTS
Mackerel and NS herring			ACC	DRTS

Note: 1) Cost complementarity in producing several outputs (CC), no complementarity in producing several (NCC), increasing cost of producing several outputs (ACC), 2) Constant returns to scale (CRTS), decreasing (DRTS), and increasing (IRTS), 3) Estimated from $\delta^2 \pi / \delta y_i \delta y_j$ for $i \neq j$. 4) Estimated from $\delta^2 \pi / \delta y_i \delta p_o$, 5) Estimated from $\delta^2 \pi / \delta y_i \delta y_i$.

The price elasticities presented in the table 6 indicate that the purse seiners are insensitive changes in market prices on landing prices of the unrestricted output and cost of fishing days. In the highly regulated industry for harvesting of the pelagic species, the insensitivity towards price changing is not surprising, but is accordance with the Le Chatelie effect (Lau, 1976).

The elasticities of intensity in the bottom of table 6 indicate that impact that a changed in quota will have both on the supply on unrestricted output but also on the demand of number of fishing days. In the first column is indicated that a 1% increase in spring spawning herring will decrease the harvesting of the unrestricted output by 0.4%. This means that the spring spawning herring and unrestricted output are produced as substitutes. That is a decrease in annual quotas will increase the harvest of other outputs. The largest elasticity of intensity is found for mackerel and NS herring meaning that a 1% decrease will increase the harvest of other outputs by 0.87 %. The harvesting of unrestricted output again is undertaken as a substitute to mackerel and NS herring that is the harvest of unrestricted will increase when the annual quotas of mackerel is reduced. In other words, the purse seiners are targeting the unrestricted mainly, because of low quota on regulated outputs rather than due market prices.

⁹ Bjørndal and Gordon (2000) also found evidence for CRTS in the fishery of spring spawning herring.

Low annual quotas induce the vessels for harvesting unrestricted species, which occur at the expense of increased harvesting costs.

The second column of table 6 indicates insignificant elasticities of intensity between quoted output and the number of fishing days. The result may be explained due to the fact that the capital intensity purse seiners are operating at a high level of capacity utilization. This means that independently of the quantity of the restricted output are operating near full capacity utilization. Moreover idle periods of fishing due to vessel repairing, annual difference is weather, and travelling time to fishing fields (regional difference) are factors significant influencing the number of active fishing days.

Table 6. *Own, cross price and intensity elasticity*

	<i>Quantity</i>	
	Unrestricted catch	Fishing days
<i>Prices</i>		
Unrestricted catch	0.0079658 (0.0155985)	-0.0205223 (0.0267277)
Fishing days	-0.0080395 (0.0179074)	-0.1205776* (0.0294158)
<i>Elasticity of intensity between restricted output and variable input/output</i>		
<i>Quantity</i>		
Spring Spawning herring	-0.3838607* (0.1763193)	0.1102562 (0.2150931)
Capelin	-0.0651425 (0.0762504)	0.0776016 (0.1266086)
Mackerel and NS herring	-0.8752341* (0.2184382)	0.1591543 (0.3058201)

Note: Standard deviation in parentheses (calculated at mean 1996 levels). The * indicates statistical significance at the 5% level.

Finally, in table 7 we are presenting the marginal cost of producing additional units of the restricted outputs and shadow values that is willingness to pay for additional quotas. The marginal costs indicate values significant values for spring spawning herring and mackerel, but not for capelin. The latter might be explained due to fact that capelin is a low value species that only have minor share (2% in 1996) of the revenues, and moreover the stock of capelin is a very unstable fishery, which means the fishery is often closed on an annual basis. In general, the largest potential is seen in the harvesting of mackerel and NS herring, where the purse seiners have a positive income of 1.85 Norwegian kroner per harvested kilo. It is therefore expected that employing a market for trading quotas, the larger vessels would be interest in buying additional quotas in the mackerel and NS herring fishery. This follows because of the shadow value of 1.85 Norwegian kroner, but also due to IRTS seen in harvesting of the mackerel and NS herring.

Table 7. *Marginal cost, and shadow values on restricted outputs per kilo (Norwegian Kroner)*

	Marginal Cost	Average landing price **	Shadow Value
Spring spawning herring	1.598* (0.720)	1.91	0.31
Capelin	0.490 (0.342)	0.32	0.32
Mackerel and NS herring	4.651* (1.170)	6.50	1.85

Note: Standard deviation in parentheses (calculated at mean 1996 levels). The * indicates statistical significance at the 5% level.

VI. Concluding Remarks

The paper studies the external effects in production of restricted and unrestricted outputs. The theory of the firms and the dual theory are used for revealing the interaction effects in production several outputs, which is based on information of the profit function at the firm level.

The empirical result indicates the presence of jointness in the production of restricted and unrestricted outputs. The restricted and unrestricted outputs are produces as substitutes in the

production process, which means that a tightening of the quotas on restricted outputs induces the firms to increase the production of unrestricted outputs. This result is important in a management setting, because it indicates that limited resources on quoted outputs induces firms to rent seeking behaviour by expanding their harvesting of unrestricted outputs. In this sense, a tightening of regulation on a species might be exported to the harvesting on other species, because the harvesting pressure in the latter fisheries goes up. In addition to this, we find for the purse seine firms that decreasing quotas for the restricted outputs lead to higher production cost, when the firms are targeting the unrestricted outputs. In the relation to the management of the pelagic species, the highest potential for economic gains are found for mackerel and North Sea herring obtained due to a willingness to pay for additional harvest quota, whereas indication of decrease returns to scale is found in these fisheries.

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