Working Papers Series

Working Paper WP89/14 June 1989

RENT DISSIPATION IN RESTRICTED

ACCESS FISHERIES

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This paper derives from my doctoral dissertation. I am grateful for suggestions, comments, and support given by committee members, Gordon Munro, Phil Neher, and Bill Schworm. Additional comments from Steven Renzetti were useful. David Reid and Paul McGillivray, in the Program, Planning, and Economics Branch, Department of Fisheries and Oceans, Vancouver, Canada, have been generous in providing access to survey data and background material. All errors and opinions are my own.

RENT DISSIPATION IN RESTRICTED ACCESS FISHERIES

ABSTRACT

Thirty-five years have passed since Gordon's seminal article on rent dissipation in open access fisheries. Restricted access fisheries, created to solve the problem, have not been successful. Three common sources of dissipated rent are: input substitution, fleet redundancy and composition. Fisheries policy has focused on finding solutions for the first source. This paper questions the wisdom of past policy by developing and implementing a methodology for the measurement of rent dissipation in restricted access fisheries. Results from the British Columbia salmon fishery suggest that regulators should have concentrated instead on improving fleet composition and removing excess vessels.

RENT DISSIPATION IN RESTRICTED ACCESS FISHERIES

1. INTRODUCTION

Thirty-five years have passed since the publication of H. Scott Gordon's [7] seminal article describing rent dissipation in open access fisheries. During this time, governments in North America have tried to solve the problem by adopting quantitative input restrictions as suggested by Gordon's model. By controlling the number of vessels or inputs per vessel, regulators have created restricted access fisheries theoretically capable of generating rent. What regulators did not anticipate was the ability of fishermen to continue dissipating rent.

Two means by which rent is dissipated in a restricted access fishery are commonly cited in the literature. Most attention has focused on the phenomenon of capital stuffing [11]. It occurs when fishermen attempt to increase their catches by using more unrestricted inputs in place of the restricted input, usually vessel size.[1] Recently, Squires [13] has reported elasticities of input substitution for the open access, New England otter trawl fishery. These elasticities are much larger than those obtained by Dupont [6] for the British Columbia salmon fishery, a restricted access fishery.[2] However, both results suggest that the harvest technology is not the fixed proportions type assumed in much of the literature.

Fleet redundancy is a second source of rent dissipation, even in restricted access fisheries [10]. It may occur when the regulator permits more than the optimal number of vessels to participate. A third less common, but potentially more important, source is a sub-optimal mix of heterogeneous vessels. Through government-determined total catch allocations for each type of vessel, less efficient vessels may continue to fish.

This paper integrates estimates of the harvest technology for vessels in a restricted access fishery with calculations of rent dissipation. Work by Squires [12, 13] and Kirkley and Strand [8] uses duality theory to estimate harvest technologies for open access fisheries, however, these authors do not examine the rent dissipation issue. Squires uses a multi-output translog profit function for the New England otter trawl fishery. The technology specifies the use of three unrestricted inputs (labor, fuel, and capital) along with a dummy variable representing the fish stock. Kirkley and Strand do not allow for any input substitution in their work on the New England, Georges Bank, trawl fishery. They adopt a generalized non-homothetic Leontief revenue function that allows fishermen to choose quantities of seven outputs subject to the use of an aggregate input.

To investigate the extent of rent dissipation in restricted access fisheries this paper focuses on the three sources identified above: input substitution, fleet redundancy, and fleet composition. A general methodology is developed and applied to the British Columbia commercial salmon fishery which has operated as a restricted access fishery with quantitative input restrictions, both on the number of vessels and on the inputs used by each vessel, for 20 years.

The methodology has three steps. First, the separate harvest technologies for each of the four vessel types used to catch salmon in British Columbia are estimated with profit maximizing output supply and input demand functions derived from a restricted profit function. The normalized quadratic [4] is chosen to specify restricted profit. This function allows the researcher to impose convexity upon coefficient estimates without losing the degrees of freedom necessary to calculate individual elasticities of substitution between all input pairs. The convexity property ensures that estimated profit-maximizing demand and supply functions will be well-behaved.[3]

The ability to impose convexity is desirable, since in step two status quo rent for the 1982 fishing season using predicted output supply and input demands is calculated. Step three simulates how the rent would change for three scenarios: a) a relaxation of tonnage restrictions per vessel; b) a reduction in total fleet size; c) and a change in fleet composition. Rent dissipation is measured as the difference between status quo rent and potential rent from each of the three simulations.

The results generated are startling, especially since the fishery in question has been subject to many years of close scrutiny and a multitude of regulations designed to prevent the loss of fishery rent encouraged by the presence of a common property resource. The results reveal that the British Columbia commercial salmon fishery, a potentially lucrative fishery that could earn annual rents equivalent to 42 percent of 1982 revenues, earned large, negative rents for the 1982 fishing season. Some factors, other than the fish stock, did not even earn their opportunity costs.

The largest source of rent dissipation comes from a suboptimal fleet composition. It permits inefficient vessel types (troll) to operate and prevents more efficient vessel types (seine) from prevailing. Government regulation has fostered this situation by imposing implicit total catch allocations on each of the four fleets. Too many vessels also contribute to rent dissipation. The deadweight loss associated with superfluous vessels is estimated at $25.7 million for 1982. This represents 16 percent of annual fishery revenues. Input substitution activities also dissipate rent, but to a lesser extent than either of two sources already mentioned. This is because the harvest technologies permit only limited substitution possibilities against input restrictions.

The remainder of the paper has five sections. Section 2 gives a brief overview of regulation in the fishery. Section 3 outlines the empirical model and estimation results. Section 4 discusses a methodology to obtain rent estimates. Section 5 presents rent calculations and Section 6 provides conclusions. An appendix discusses data sources and construction and gives the coefficient estimates for the restricted profit functions.

2. REGULATION IN THE B.C. SALMON FISHERY

The commercial salmon fishery in British Columbia is the province's most important fishery.[4] Prior to 1968 it was open access. The presence of too many vessels contributed to severely depleted fish stocks and spurred the adoption of regulations to prevent overfishing and rent dissipation.

Beginning with the 1969 fishing season Federal legislation restricted the number of salmon-fishing vessels. Vessels with an established presence received a license authorizing the right to capture salmon. Some 5800 salmon licenses were issued. However, this number had no claim to optimality. Furthermore, fixing the number of vessels did not prevent fishing effort per vessel from increasing. The Department of Fisheries and Oceans, the Federal agency responsible, restricted the size of each vessel in 1971 by putting a limit on its tonnage. The rest of the decade saw successive rounds of new regulations and subsequent efforts by fishermen to circumvent them. In spite of these restrictions, fish stocks continued to decline amid great concern about overcapacity of the commercial salmon fishing fleet.

In 1982 the Royal Commission on Pacific Fisheries Policy [10] recommended a rationalization of the salmon fishery. The main goal was to reduce the salmon fleet by half -- to about 2500 vessels -- within a ten year period. Owners of remaining vessels were to pay royalties for the right to catch salmon. By taxing rents from the fishermen, Pearse hoped to prevent rent dissipation through input substitution activities. He also noted that the wrong mix of vessel types might lead to reduced rents from the fishery, that is, implicit total quotas for each of four different vessel types permitted less efficient types to remain in the fishery.[5] It had often been claimed that seine vessels could take the entire catch at least cost, thereby increasing fishery rent.

3. EMPIRICAL MODEL

An examination of rent dissipation must begin with the harvest technology. In a regulated fishery, this can be represented by a restricted profit function. It assumes that the fishing firm is in partial static equilibrium [1]. This is a useful approach for describing the short-run behaviour of firms subject to input controls.[6]

The fishing firm maximizes profit by choosing the quantity of output supplied, Y, and the quantities of variable or unrestricted inputs demanded, $\mathbf{X} = (X_1, X_2, ..., X_N)$. The firm has constraints on the use of certain inputs, $\mathbf{Z} = (Z_1, Z_2, ..., Z_M)$. Restrictions are in the form of upper bounds on the firm's use of these inputs and are assumed to be binding.

Equation (1) gives the restricted profit function.

$$\pi^R (P_Y, \mathbf{W}, \mathbf{Z}) = \text{Max}_{X,Y} \{ P_Y.Y - \mathbf{W}^T\mathbf{X}; \ (Y, \mathbf{X}; \mathbf{Z}) \in T \} \quad (1)$$

$$\text{for } P_Y > 0, \ \mathbf{W} >> 0_N, \ \mathbf{Z} \leq 0_M$$

P_Y is the output price. The vector, $\mathbf{W}$, represents market prices for the variable inputs. When the restricted profit function fulfils a set of well-known properties [3], it is dual to a harvest production function $F(\mathbf{X};\mathbf{Z})$ and to a production possibilities set, T.

A specific functional form must be chosen for the empirical work. This paper uses a normalized, quadratic restricted profit function [4]. In addition to allowing the researcher to impose convexity in prices without losing flexibility,[7] this function has two features that make it a suitable model for a study of rent dissipation. First, the estimating equations are in levels, not shares. This facilitates subsequent simulations to obtain estimates of fishery rent described in Section 4. Second, estimates of the optimal amount of tonnage (Z_T^*) per vessel are needed to calculate rent dissipation. The equation derived from the normalized quadratic describing Z_T^* is linear in the estimated coefficients.[8]

To represent the fish harvest technology used in the British Columbia commercial salmon fishery, a normalized quadratic restricted profit function is given in equation (2) for 4 variable quantities (one output and three variable inputs) and 3 fixed factors. It is assumed that a separate technology exists for each of the 4 vessel types.[9]

$$\pi^R(P,Z) = 1/2\ (\ \Sigma_j\ \alpha_j Z_j\ \ \Sigma_i\ \ \Sigma_k\ a_{ik}P_iP_k)/P_Y$$

$$+\ 1/2(\ \Sigma_i\ \beta_i P_i\ \ \Sigma_j\ \ \Sigma_h\ b_{jh}Z_jZ_h)/Z_S \qquad (2)$$

$$+\ \ \Sigma_i\ \ \Sigma_j\ c_{ij}P_iZ_j$$

$$+\ (\ \Sigma_i\ \beta_i P_i\ \ \Sigma_j\ b_jZ_j)/Z_S$$

$$+\ 1/2(\ \Sigma_i\ b_0\ \beta_i P_i)/Z_S\ +\ \ \Sigma_i\ c_iP_i$$

Prices are indexed by i,k in the following order: P_Y (price of output, ie., salmon catch), P_L (price of labor), P_F (price of fuel), and P_G (price of gear and equipment).[10] In addition to a restriction on tonnage, Z_T, fishermen face restrictions on the use of two other inputs. They are the number of fishing days and the stock of fish. Indexing of fixed quantities j,h is as follows: Z_S (stock of fish), Z_T (tonnage), Z_D (number of fishing days). Since the function is normalized, numeraires of P_Y and Z_S are chosen.[11] The appendix describes the sources and construction of the data.

For each vessel type a system of four variable quantity equations, ((3)-(4)), is obtained from (2) by application of Hotelling's Lemma.

$$\frac{\partial \pi^R}{\partial P_Y} = Y^*(P_Y,\ P_L,\ P_F,\ P_G;\ Z_S,\ Z_T,\ Z_D)$$

$$= -1/2\ (\ \Sigma_j\ \alpha_j Z_j\ \ \Sigma_i\ \ \Sigma_k\ a_{ik}P_iP_k)/P_Y^2 \qquad (3)$$

$$+\ 1/2\ (\beta_Y\ \ \Sigma_j\ \ \Sigma_h\ b_{jh}Z_jZ_h)/Z_S$$

$$+\ \ \Sigma_j\ c_{Yj}Z_j\ \ +\ \beta_Y\ (\ \Sigma_j\ b_jZ_j)/Z_S$$

$$+\ 1/2\ b_0\,\beta_Y\,/Z_S\ +\ c_Y$$

$$\frac{\partial \pi^R}{\partial P_{Xi}} = X_i^*(P_Y, P_L, P_F, P_G; Z_S, Z_T, Z_D)$$

$$= (\Sigma_j \alpha_j Z_j \Sigma_k a_{ik} P_k)/P_Y \quad (4)$$

$$+ 1/2(\beta_i \Sigma_j \Sigma_h b_{jh} Z_j Z_h)/Z_S$$

$$+ \Sigma_j c_{ij} Z_j + \beta_i (\Sigma_j b_j Z_j)/Z_S$$

$$+ 1/2\, b_0\, \beta_i / Z_S + c_i \qquad \text{all } X_i = L, F, G$$

Coefficients are: α_j, a_{ik}, β_i, b_{jl}, c_{ij}, b_j, c_i, b_o.[12] Equations (3)-(4) give the necessary cross-equation and symmetry restrictions, ie., $a_{ik} = a_{ki}$ in all equations for ik and $b_{jh} = b_{hj}$ in all equations and for each jh. Since the restricted profit function is linearly homogeneous in prices, the functions in (3)-(4) are homogeneous of degree zero. The restricted profit function satisfies convexity in prices globally (and locally) whenever the A matrix, formed from the a_{ik} coefficients, is positive semi-definite.

A re-parameterization of the A matrix imposes convexity [14]. The product of a matrix D, a lower triangular matrix with zeroes in the first column, and its transpose replaces the A matrix, ie., $A = DD^T$. Multiplicative and additive combinations of the elements of D are used to obtain estimates of the a_{ik} coefficients. The 'd' coefficients must be estimated using nonlinear techniques.

For each of the 4 different vessel types: seine, gillnet, troll, and gillnet-troll, equations (3)-(4) are estimated as a system of seemingly unrelated regressions. Data are cross-sectional and come from the 1982 fishing season. The number of observations for each of the vessel types is: seine (21), gillnet (80), troll (84), and gillnet-troll (60). Estimated a_{ik} coefficients are checked for acceptance of convexity in prices. Since estimates for one of the vessel types (troll) are consistent with this characteristic, no further estimation of this sample is required. However, the other samples are re-estimated using nonlinear maximum likelihood.[13]

The appendix gives estimated coefficients values and associated standard errors for each of the four samples (Tables III to VI).[14] The estimated equations are used in the next section to obtain predicted quantities of output, variable inputs, optimal tonnage, and fishery rents for different simulations. Comparisons of rent across the simulations show the extent to which input substitution, overcapacity, and fleet composition may lead to rent dissipation. For the British Columbia salmon fishery each of these sources of rent dissipation may be attributed to inefficient government policy.

4. MEASURING RENT DISSIPATION

This paper measures the extent of three types of a particular class of rent dissipation caused by a Class II common property problem [9].[15] This may occur when the regulator restricts the total annual harvest -- by means of an annual restriction on the total allowable catch (TAC) --, but cannot control the actions of individual members of the fleet and the total amount of effort directed at the fishery.

The first means of dissipating rent to be examined is that resulting from input restrictions upon individual fishing firms. In order to increase his catch, each fisherman may substitute unregulated inputs for restricted inputs. If the fisherman could use the optimal quantity of the restricted input and fewer unrestricted inputs, he could lower his harvesting costs and increase the rent from the fishery.

Calculation of this type of rent dissipation requires estimates of the relevant input and output quantities to form an estimate of restricted profit.[16] Rent is the difference between estimated restricted profit and tonnage expenditures.[17] Tonnage expenditures are the product of tonnage and the unit capital services price.[18]

Rent dissipation caused by input substitution of the individual fisherman is measured by the difference between potential rent, $\pi(Z_T{}^*)$, which uses optimal tonnage to obtain predicted quantities, and status quo rent, $\pi(Z_T{}^A)$, which uses actual tonnage. An estimate of optimal tonnage, $Z_T{}^*$, is found by defining total profit as restricted profit minus tonnage expenditures as in equation 5.

$$\pi^T(P,Z) \quad = \quad \pi^R(P;Z) \ - \ r\, Z_T \qquad (5)$$

In this equation, r is the unit capital services price of the restricted input, tonnage. Differentiating π^T with respect to Z_T yields a function for the profit-maximizing level of tonnage demanded by the vessel. The formula obtained from a normalized quadratic restricted profit function is linear in both estimated coefficients and variables (equation 6).

$$\begin{aligned} Z_T{}^* \quad = \quad & -[Z_S \ / \ (b_{TT} \ \ \Sigma_i \, \beta_i P_i)]^* \\ & [\, r + (1/2 \ \ \Sigma_i \ \Sigma_k \, a_{ik} \ P_i P_k / P_Y) \\ & + \ \Sigma_i \, \beta_i P_i \ (b_{TD} + b_T / \ Z_S) + \ \Sigma_i \, c_{iT} P_i \ ] \end{aligned} \qquad (6)$$

Summing the rent earned by each vessel over all vessels in the sample gives estimates of within sample status quo rent and potential rent. Their difference measures the extent of dissipated rent attributable to input substitution by the sample of 245 vessels, representing 5 percent of the salmon fleet.

Turning to rent dissipation at the industry level, redundant fleet capacity may have resulted from an incorrect choice by the government of the number of participants at the start of the program. **Status quo** rent for the entire fishery is estimated as the sum of individual vessel rents over all vessels that participated in the fishery in 1982. Potential rent from a reduced vessel population is found as the sum of rent over the minimum number of vessels needed to take the total allowable catch (TAC). The difference between these two rents gives an estimate of rent dissipation attributable to an excessive number of participants.[19]

To the extent that capital is non-malleable, some portion of the additional cost of too many vessels may be a deadweight loss to society. An estimate of this loss may be found by multiplying the amount of excess capital (total tonnage of vessels in excess of optimal) by the capital services price.

Even if the number of participants is optimal, the mix may be incorrect. Government regulations may prevent lower cost vessels from prevailing. To obtain an estimate of potential rent using a mix of vessel types other than the actual one, it is assumed that the entire fleet is composed of one vessel type. Industry rents are calculated assuming each of the four vessel types prevails in turn.

5. RESULTS

Table I presents the within sample rents. Status quo rent is calculated by using actual tonnage and associated output and variable input quantities. Potential rent is found by replacing actual tonnage with optimal tonnage to predict associated output supply and input demand quantities. The average values for actual and optimal tonnage are: seine (23.9, 21.5), troll (9.2, 21.0), gillnet-troll (7.0, 7.5), and gillnet (6.1, 1.7). Using an estimate of the asymptotic standard error for the variable, Z_T*, one can test the hypothesis that the actual and optimal tonnage values are not significantly different from each other. Tests using the asymptotic standard errors for estimated optimal tonnages do not reject this hypothesis.[20]

The numbers in Table I suggest that gillnet and troll vessel types generate within sample status quo rents that are negative. Since these are annual rents, this means that vessels of this type on average are not earning enough revenue in one year to provide an opportunity cost return for all inputs. There are several reasons for this finding. On the one hand, harvesting costs might be overstated. This may be the case if the depreciation and opportunity cost rates used in the capital services price are too high. Alternatively, the relevant opportunity cost of labor may be lower than the wage used. On the other hand, revenue estimates may be too low. This may happen when some catches go unreported.

According to the model developed and estimated in this paper, within sample status quo rents for 245 vessels are $1,062,600 for the 1982 salmon fishing season. If, instead, vessels could choose the optimal tonnage and associated output and variable inputs, potential fishery rent would increase four-fold to $4,406,700. Therefore, a large amount of potential rent is being dissipated by the input substitution activities of the fishermen.

Fishery rents at the industry level are shown in Table II. In addition to providing an estimate of status quo rent, this table gives results for potential rent obtained from three different simulations. Potential rent #1 results from abolishing fleet redundancy. Potential rent #2 is obtained when fleet redundancy is abolished and tonnage restrictions removed. Potential rent #3 results from a fleet entirely composed of only one vessel type using optimal tonnage.

The presence of too many vessels causes negative status quo rents to be earned by three of the four vessel types and for the industry as a whole in 1982. The numbers of redundant vessels are: 46 (gillnet-troll), 182 (seine), 195 (gillnet), and 581 (troll). Their total represents 22 percent of the 4528 vessels. The loss of potential fishery rent attributable to fleet redundancy is large. Rent could rise to $14,129,000 from its current value of -$38,695,000. Since total salmon revenue in 1982 was $164.9 million, potential rent # 1 is equivalent to 9 percent of the value of the catch. The amount of excess tonnage associated with the current number of vessels is 37 percent. The deadweight loss associated with fleet redundancy can be measured by the sum of the product of the number of superfluous vessels in each sample and the non-salvageable capital costs per vessel type. If it is assumed that the fishing vessel has no value outside the fishery, then its entire capital cost is nonsalvageable. For the fleet, the deadweight loss is $25.7 million in 1982. This represents about 2/3 of the negative status quo rent.

The fourth column shows the extent to which potential rents could increase further if the minimum number of vessels using the optimal tonnage were to take the 1982 Total Allowable Catch. Total industry rents would rise to $35,486,000 (22 percent of the total value of salmon caught in 1982).

One final simulation remains. If the seine fleet alone were to take the salmon, potential fishery rent would rise to $69,436,000. The second most efficient vessel type is the gillnet-troll. It is capable of generating rent equal to $47,751,000 in 1982. The troll vessel type never generates a positive rent from the fishery in any simulation. Experts believe this vessel type functions best when harvesting small quantities of higher quality fish selectively.

6. CONCLUSIONS

This paper presents estimates of the harvest technology and the amount of rent dissipated by fishermen in a restricted access fishery. Rent dissipation may take place because there are inefficient regulations that include restrictions on input usage per vessel, the number of participating vessels, and the mix of heterogeneous vessels. A comparison of status quo rents with potential rents -- obtained by adopting more efficient regulations -- gives estimates of the amount of rent dissipated.

Using data from the British Columbia salmon fishery, the largest gain in fishery rent would come from a move to a seine only fleet. A fleet composed of this vessel type alone could generate a rent equal to 42 percent of total fishery revenue in 1982. This represents a substantial loss to society. Yet, the government has been reluctant to tamper with the historical division of catch among user groups and has continued to permit inefficient vessels to operate by maintaining total catch allocations for each fleet.

Ridding the fishery of redundant vessels would provide the second largest source of rent gain. Pearse [10] proposed that the salmon fleet be cut in half over a ten year period. Pressure from various interest groups has prevented this needed rationalization of the fishery.

By contrast, for the British Columbia commercial salmon fishery, rent dissipation caused by input substitution is the least important of the three sources of rent dissipation identified and measured in this paper. This result is not surprising, since Dupont [6] shows that, while input substitution possibilities exist, they are not large. Government regulations have concentrated on preventing input substitution. Results presented in this paper suggest that the regulator should have devoted more attention to forestalling the more serious avenues of rent dissipation such as fleet redundancy and the continued participation of inefficient vessels.

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TABLE I

ESTIMATED RENTS FOR SAMPLE VESSELS

(1982 Canadian Dollars)

Vessel Type	# of Vessels	Status Quo Rent[a]	Potential Rent[b]
Seine	21	919,000	3,012,000
Gillnet	80	-128,000	484,400
Troll	84	-238,000	-117,600
Gillnet-Troll	60	510,000	1,027,700
Total	245	1,062,600	4,406,700

[a] Rent obtained using actual tonnage values.

[b] Rent obtained using optimal tonnage values.

TABLE II

ESTIMATED RENTS FOR B.C. SALMON FISHERY

(1982 Canadian Dollars '000)

Vessel Type	Statuo Quo Rent[a]	Potential Rent #1[b]	Potential Rent #2[c]	Potential Rent #3[d]
Seine	-2,935	15,544	17,673	69,436
Gillnet	-9,253	-3,775	4,944	28,968
Troll	-33,086	-5,775	-2,035	-20,256
Gillnet-Troll	6,579	8,135	14,904	47,751
Total	-38,695	14,129	35,486	n/a

[a] Rent obtained using actual tonnage values and number of vessels in 1982.

[b] Rent obtained using actual tonnage values and minimum number of vessels.

[c] Rent obtained using optimal tonnage values and minimum number of vessels.

[d] Rent obtained using optimal tonnage values and minimum number of vessels of one type only.

APPENDIX

Three data sources are combined to construct price and quantity information from the 1982 fishing season for each vessel. The first, a cross-sectional survey of Pacific Coast fishermen for 1982, gives expenditure and gear/equipment inventory information by vessel for a variety of categories. It also provides data on the number of fishing days and vessel tonnage. The second, 1982 Sales, provides revenue and output information. Data on prices for five species of salmon are used to calculate a Divisia output price index. Opportunity cost wages are constructed for labor in a manner similar to Squires (1987b). Average weekly earnings in an industrial composite category by region, based upon each vessel's homeport region, are used. Esso Canada Ltd. has provided marine fuel prices for 11 centres. The gear/equipment input, consisting of nets, lines, etc., is taken to be a malleable capital good whose services are not exhausted in one year. A rental cost of gear is calculated for each component. It includes the cost of repair and maintenance. Quantity and unit rental price data are used to construct a Divisia gear price index.

Stock abundance varies across fishing grounds and each vessel encounters a different stock depending upon areas fished. Information on catch and escapement in 29 management areas, defined for regulatory purposes, is used to construct an index of stock abundance. For each vessel, stock encountered is calculated as the relative abundance in each area weighted by the number of weeks the vessel fished in that area.

Since data on the opportunity cost of a newly constructed vessel is not readily available, information from the survey of Pacific Coast vessel-owners is used. Current market values for the sample of vessels are averaged over each vessel type to form an estimate of the purchase price of the vessel. This is divided by the average number of tons. The resulting stock price per ton is adjusted for depreciation and the opportunity cost of capital to obtain a capital services price, r. The current market values obtained in the manner described above are similar to asking prices in classified advertisements for recently built vessels.

TABLE III

PARAMETER ESTIMATES - SEINE

Variable Name	Coefficient Value	Standard Error	Variable Name	Coefficient Value	Standard Error
d_1	-0.139[a]	0.060	c_{YD}	-1.670[a]	0.721
d_2	-0.272[b]	0.151	c_Y	1.220	1.953
d_3	-0.101E-05	0.308	c_{LS}	0.199	0.661
d_4	0.323[a]	0.106	c_{LT}	1.473	1.365
d_5	0.665E-06	0.232	c_{LD}	-2.413[a]	0.614
d_6	0.601E-07	0.124	c_L	-2.478	1.988
b_{TT}	3.498	2.696	c_{FS}	0.189	1.153
b_{TD}	-3.728[b]	2.283	c_{FT}	-1.414	2.023
b_{DD}	-1.424[a]	0.704	c_{FD}	-2.999[a]	0.949
b_0	-3.581	3.001	c_F	-1.030	2.625
b_T	-0.418	3.040	c_{GS}	13.711[a]	7.744
b_D	5.411[a]	1.103	c_{GT}	19.771[a]	10.877
c_{YS}	-0.013	0.708	c_{GD}	-9.420[a]	5.979
c_{YT}	1.678	1.538	c_G	-31.171[a]	13.713

[a] 5% significance

[b] 10% significance

TABLE IV

PARAMETER ESTIMATES - GILLNET

Variable Name	Coefficient Value	Standard Error	Variable Name	Coefficient Value	Standard Error
d_1	-0.380[a]	0.076	c_{YD}	0.248[a]	0.053
d_2	0.023[a]	0.008	c_{YL}	0.271	0.319
d_3	0.246E-06	0.018	c_{FS}	0.054	0.074
b_{TT}	0.346[b]	0.259	c_{FT}	-0.093	0.148
b_{TD}	0.059[b]	0.057	c_{FD}	-0.176[a]	0.038
b_{TL}	-0.259	0.297	c_{FL}	-0.419[a]	0.204
b_{DD}	-0.032[a]	0.017	c_{GS}	0.010	0.058
b_{DL}	-0.032[a]	0.017	c_{GT}	0.020	0.128
b_{LL}	0.285	0.285	c_{GD}	-0.049[a]	0.029
c_{YS}	0.103	0.125	c_{GL}	-0.361[a]	0.177
c_{YT}	0.200	0.238			

[a] 5% significance

[b] 10% significance

TABLE V

PARAMETER ESTIMATES - TROLL

Variable Name	Coefficient Value	Standard Error	Variable Name	Coefficient Value	Standard Error
a_{LL}	0.133[a]	0.026	c_{YD}	3.101[a]	0.757
a_{LF}	0.023	0.036	c_{Y}	-1.441[b]	0.972
a_{LG}	-0.855E-03	0.003	c_{LS}	-0.643[a]	0.223
a_{FG}	0.218E-02	0.003	c_{LT}	0.404	0.321
a_{FF}	0.434[a]	0.137	c_{LD}	-0.176	0.259
a_{GG}	0.680E-03	0.001	c_{L}	-1.606[a]	0.394
b_{TT}	-0.021	0.103	c_{FS}	-0.561[a]	0.261
b_{TD}	-0.078	0.103	c_{FT}	-1.915[a]	0.333
b_{DD}	-0.079	0.197	c_{FD}	-0.734[a]	0.291
b_{0}	0.125E-02	0.289	c_{F}	-0.643[b]	0.455
b_{T}	0.109E-02	0.173	c_{GS}	-0.151	1.148
b_{D}	0.151	0.194	c_{GT}	1.061	1.155
c_{YS}	2.615[a]	0.709	c_{GD}	-0.3210	1.246
c_{YT}	2.251[a]	0.729	c_{G}	-1.644	1.573

[a] 5% significance

[b] 10% significance

TABLE VI

PARAMETER ESTIMATES - GILLNET-TROLL

Variable Name	Coefficient Value	Standard Error	Variable Name	Coefficient Value	Standard Error
d_1	0.128	0.111	c_{YD}	0.453[a]	0.236
d_2	-0.127	0.245	c_Y	-0.370	1.436
d_3	-0.293[a]	0.127	c_{LS}	-0.033	0.187
d_4	0.591E-02	0.028	c_{LT}	-1.566[a]	0.569
d_5	0.572E-02	0.029	c_{LD}	-0.260[a]	0.096
d_6	0.145E-08	0.040	c_L	0.792	0.663
b_{TT}	-2.681[a]	1.557	c_{FS}	-0.156	0.197
b_{TD}	0.458[a]	0.204	c_{FT}	-1.479[a]	0.594
b_{DD}	0.073[b]	0.053	c_{FD}	-0.364[a]	0.104
b_0	-3.490	1.910	c_F	1.161	0.682
b_T	3.038[a]	1.618	c_{GS}	40.551[a]	22.139
b_D	-0.567[a]	0.216	c_{GT}	-80.144[b]	61.727
c_{YS}	0.273	0.558	c_{GD}	3.279[a]	1.097
c_{YT}	2.697[a]	1.267	c_G	-18.401	68.517

[a] 5% significance

[b] 10% significance

Endnotes

1. In practice, this is usually a vessel's tonnage, a commonly used measure of size. Tonnage refers to the volumetric displacement of the vessel in the water.

2. Dupont [6] uses a restricted profit function defined over both variable and restricted inputs to calculate elasticities of intensity. An elasticity of intensity describing the relationship between a variable and a restricted input is found by differentiating the variable input demand function with respect to restricted input. When firms are not able to choose the quantities of all inputs, this elasticity is more appropriate than an elasticity of substitution defined for two variable inputs.

3. Both Squires [12, 13] and Kirkley and Strand [8] report that convexity is rejected by the data used to estimate their models.

4. Most recent statistics, available for 1987, show that annual salmon revenues amount to $212 million. In that year, salmon accounted for 35 % of quantity and 50% of landed value of all catches [2].

5. Four types of vessels are used. They are seine, gillnet, troll, and a combination of the last two called gillnet-troll. Each type exhibits a number of unique characteristics, but all use some combination of labor, fuel, gear/equipment and capital (vessel) inputs. Seine and gillnet vessels use a variety of nets to entrap the salmon. Troll vessels use lines, hooks, and bait to entice the salmon. Gillnet-troll vessels use both nets and troll lines. Seine vessels have the largest tonnage and use from 4 to 7 people. Troll vessels are slightly smaller. Gillnet-troll and gillnet vessels are at the lower end of the spectrum.

6. Dupont [6] discusses the inappropriateness of the alternative assumption of full static equilibrium, used by Squires [12, 13], when firms are unable to choose the quantities of all inputs.

7. It is possible to impose convexity on a translog, but that function's ability to identify individual elasticities is then impaired.

8. The corresponding equation derived from a translog is nonlinear. Estimates of the optimal tonnage can only be obtained through approximation techniques.

9. Because gillnet vessels are usually single person operations this sample is estimated with only two variable inputs, fuel and gear. Labor is added to the set of fixed factors.

10. These prices are assumed to be exogenous. In the B.C. salmon fishery each vessel is small enough relative to the total number (4528 in 1982) to preclude its exercising market power.

11. Additional estimation reveals that choice of a price numeraire makes little difference to parameter estimates and even less difference to elasticity estimates.

12. Because of the linear relationships between the columns in the matrix A (composed of the elements [a_{ik}]) the first row and column of A, eg., a_{YK} through a_{KY} (K = Y, L, F, G) are taken to be vectors of zeroes. Diewert and Wales [5] note that the α_j (j = S, T, D) may be chosen arbitrarily and suggest they be set equal to $1/Z_j^1$, where Z_j^1 is the fixed factor vector for the first observation. Likewise, the β_i (i = Y, L, F, G) may be set equal to $1/P_j^1$. This convention is adopted here.

13. Space limitations preclude reporting of the equations used, but the author will supply them upon request. They are similar to those in (3)-(4) with the exception that the a_{ik} coefficients are replaced by nonlinear combinations of d coefficients, as follows: $a_{LL} = d_1^2$, $a_{LF} = d_1 d_2$, $a_{LG} = d_1 d_4$, $a_{FF} = d_2^2 + d_3^2$, $a_{FG} = d_3 d_5 + d_2 d_4$, and $a_{GG} = d_4^2 + d_5^2 + d_6^2$.

14. Own-price elasticities of supply and demand reported elsewhere [6] show responses to be generally inelastic. Fuel and labor are substitutes in most cases for gear, whereas labor and fuel are complements. Labor and gear are substitutes for the restricted input, tonnage, for two samples (seine and troll). Fuel is a complement for tonnage in all samples. With the exception of gear, these elasticities are inelastic.

15. Other forms of rent dissipation not measured in this paper include congestion and stock

externalities, and rent dissipation through the processing sector. Nor is intertermporal rent dissipation caused by overfishing of the stock -- this is the Class I common property problem identified by Gordon [7] -- measured in this paper, since the regulator chooses the annual total allowable catch.

16. Profit-optimizing output supply and input demands for the representative vessel are found by substituting sample average prices and levels of restricted inputs into the estimated equations (3)-(4).

17. Rent calculated in this way is a return not only to the unpriced fish input, but also to fishing days. Since returns to fishing days occur largely because of the existence of the fish stock, the total return is ultimately attributable to the fish stock.

18. See Appendix for a description of the construction of this variable.

19. For all simulations, it is assumed that the fishing technology does not change and is represented by the estimated harvest technology.

20. It will be noted that, for some vessel types, the optimal tonnage is smaller than the actual. The reason why fishermen do not adopt the optimal tonnage when the government does not impose lower bound restrictions upon tonnage is that tonnage may not be a completely divisible input. Therefore, vessel-owners will continue to use a given vessel size when the difference between the actual and the optimal is small.