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INPUT CONTROLS IN A FISHERY:

SUCCESS OR FAILURE?

Diane P. Dupont

Assistant Professor

Department of Agricultural Economics and Business,

University of Guelph, Guelph, Ontario, N1G 2W1, Canada.

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Fisheries

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ABSTRACT OF
INPUT CONTROLS IN A FISHERY: SUCCESS OR FAILURE?

This paper examines the effectiveness of input controls in a fishery in preventing rent dissipation. The paper shows that conventional elasticities cannot be used to measure input substitution when firms face input restrictions. The paper presents a new elasticity measure and illustrates its usefulness with data from the British Columbia salmon fishery.

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Introduction

Fish resources generate a resource rent if they are taken at a low cost relative to their market value. Given the absence of property rights to fish, however, competition among fishermen can result in a complete dissipation of rent (Warming, 1911; Gordon, 1954). To preserve resource rents regulators often use input restrictions (Christy, 1973; Karpoff, 1987). Their success rests upon whether fishermen can find substitutes (Rettig, 1984).

Past research is divided over the issue of the substitution possibilities open to fishermen. Crutchfield (1979) argues that the production function is effectively of the fixed proportions type, while Scott (1979) claims that the fishing technology allows much scope for substitution. Empirical work by Strand, Kirkley, and McConnell (1981) and Squires (1987a, 1987b, 1987c) supports Scott's position. In particular, Squires uses data from the open access, unregulated New England otter trawl fishery to estimate a translog profit function with variable inputs: labor, fuel, and capital. He computes Allen elasticities of substitution that provide evidence of large substitution possibilities between input pairs.

This paper argues that these conventional elasticities of substitution cannot be used to evaluate the success of a regulatory program that restricts the use by fishermen of certain inputs. The reason for this view is that these elasticities are obtained from a model that assumes that all inputs can be chosen freely by the fisherman. As an alternative method for testing the degree of substitution in a regulated fishery subject to input controls, this paper proposes that the partial static equilibrium framework of Brown and Christensen (1979) be used to obtain estimates of the elasticity of intensity (Diewert, 1974). This elasticity describes the relationship between an unrestricted and a restricted input. Using this framework the paper shows that conventional elasticities of substitution are biased relative to elasticities of intensity and that the direction of the bias is related to the magnitude of the restricted input's own price elasticity of input demand.

The potential usefulness of this alternative methodology to fisheries regulators is illustrated with the empirical results obtained by using data from an important Canadian regulated fishery, the British Columbia commercial salmon fishery. Since 1969 the number of vessels has been restricted and since 1971 the government has put an effective upper bound on the tonnage (size) of each vessel as a way of controlling fishing effort per vessel. Results in this paper show that the regulation has not been successful. Labor and gear inputs are found to be direct substitutes for tonnage for two of the four vessel types (seine and troll). Research has identified these vessel types as best equipped to sidestep input restrictions and dissipate fishery resource rent (Pearse, 1982; Dupont, 1990).

Modelling Substitution Possibilities Between Unrestricted and Restricted Inputs

A partial static equilibrium model (Brown and Christensen, 1979) can be used to describe short-run behaviour for firms subject to input restrictions. The firm maximizes restricted profit (equation 1) by choosing the quantity of output supplied, y, and the quantities of variable or unrestricted inputs, $X = (x_1, x_2, ..., x_n)$, subject to exogenous input and output prices and constraints on the use of certain inputs, $Z = (z_1, z_2, ..., z_m)$. These constraints take the form of upper bounds on the firm's use of these inputs; they are assumed to be binding. The output price is denoted by p_y. The vector, W, represents market prices for the n variable inputs. When the restricted profit function in equation (1) fulfills a set of well-known properties defined in Diewert (1974), it is dual to the underlying production function F(X;Z) and to the production possibilities set, T.

$$(1) \quad \pi^r (p_y, W, Z) = \text{Max}_{x,y} \{p_y y - W^T X; (y, X; Z) \in T \}$$

Elasticities are obtained from the output supply and input demand equations which, in turn, are derived by differentiating the restricted profit function with respect to prices. To determine whether variable inputs are complements or substitutes, it is sufficient only to know the cross-price elasticities of input demand (since conventional Allen elasticities of substitution are transformations of the cross-price elasticities). (Since the formulae for these elasticities are well known, they are not repeated in this paper.) Inputs are substitutes when the cross-price elasticity is positive and complements when it is negative.

Measures of substitution possibilities between unrestricted and restricted inputs are obtained with elasticities of intensity (Diewert, 1974). Equation (2) defines these elasticities. A negative elasticity shows a substitute relationship and a positive elasticity, a complementary one. For example, if the value of the elasticity between tonnage and gear is -1.5, this says that an incremental increase in tonnage, the restricted input, would result in substantial reduction in the optimal employment of gear, an unrestricted input, by the fishing firm. Hence, the firm regards these two inputs as substitutes.

$$(2) \quad \xi_{ij} = \frac{\partial x_i(p_y, W; Z)}{\partial z_j} \cdot \frac{z_j}{x_i} \qquad i = 1,2,...n \text{ and } j = 1,2,...m$$

The relationship between the cross-price elasticity of input demand and the elasticity of intensity is established by defining a full static equilibrium profit function as one in which restricted inputs are treated as variable. Then, it can be shown that the cross-price elasticity of input demand between inputs x_i and z_j is the product of the own-price elasticity of z_j and the elasticity of intensity between inputs x_i and z_j. Therefore, if the own-price elasticity of demand for z_j is elastic, then the cross-price elasticity of demand will be greater in magnitude than the corresponding elasticity of intensity.[1] The converse is true if the own-price elasticity for z_j is inelastic.

Empirical Specification

This research estimates a normalized quadratic restricted profit function (Diewert and Ostensoe, 1987) for each of the four vessel types (seine, troll, gillnet, and gillnet-troll) in the British Columbia salmon fishery. This flexible functional form has two main advantages over alternative forms such as the translog (Squires, 1987a, 1987b, 1987c) and the generalized leontief (Kirkley and Strand, 1988). First, the normalized quadratic allows the researcher to retrieve the fixed factor parameter estimates required to calculate the elasticities of intensity by estimating a system of output supply/unrestricted input demand equations. There is no need to assume equilibria in markets for restricted inputs (McKay, Lawrence, and Vlastuin, 1983). Second, a researcher can impose convexity in prices on parameter estimates of the restricted profit function and continue to identify separate elasticities between individual pairs of inputs. Previous estimates of fishing technology have not satisfied the convexity property (Squires, 1987a, 1987b, 1987c; Kirkley and Strand, 1988), although these findings may result from multicollinearity and data aggregation.

For this paper the normalized quadratic restricted profit function is defined over four variable quantities (one output and three variable inputs, e.g., fuel, labor, and gear/equipment) and three restricted inputs (vessel tonnage and number of fishing days, both restricted by the regulating agency, and the stock of fish available for the season, restricted by nature). Equation (3) shows the form of the function.[2]

$$
\begin{aligned}
(3) \quad \pi^{r}(P, Z) \quad = \quad & 1/2\,(\textstyle\sum_j \alpha_j\, z_j \sum_i \sum_k a_{ik}\, p_i p_k)/p_y \\
& + 1/2(\textstyle\sum_i \beta_i\, p_i \sum_j \sum_h b_{jh}\, z_j z_h)/z_s \\
& + \textstyle\sum_i \sum_j c_{ij}\, p_i z_j \; + (\sum_i \beta_i p_i \sum_j b_j z_j)/z_s \\
& + 1/2(\textstyle\sum_i b_0\, \beta_i p_i)/z_s \; + \sum_i c_i p_i
\end{aligned}
$$

Variable quantity prices are indexed by i,k in the following order: p_y (output price), p_l (labor), p_f (fuel), and p_g (gear and equipment). 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.[3] Define the matrix A with elements a_{ik}. The linear relationships between rows and columns in the matrix A caused by linear homogeneity require the first row and column of A, eg., a_{yk} through a_{ky} (k = y, l, f, g) to be vectors of zeroes. The parameters to estimate are: α_j, a_{ik}, β_i, b_{jl}, c_{ij}, b_j, c_i, b_o.[4]

Data come from a cross-sectional random survey of Pacific Coast fishermen for 1982. This survey gives expenditures, input quantities, and vessel characteristics by vessel. A second data set with catch and revenue information complements the survey data. Only those vessels that are dedicated to salmon are chosen, since the other main species (herring and halibut) are regulated differently. A Divisia index is calculated for the aggregate output price and the associated aggregate quantity index for each vessel. Knowledge of each vessel's homeport permits the calculation of regional opportunity cost wages for labor (Squires, 1987c) using average weekly earnings in an industrial composite category. Marine fuel prices for 11 centres come from Esso Canada Limited. The gear/equipment input, consisting of nets, lines, etc., is a malleable capital good whose services are not exhausted in one year. A rental cost of gear is calculated for each component. Quantity and unit rental price data are used to construct a Divisia gear price index for each vessel. Data on catch and escapement in each of 29 management areas are used to calculate fish stock abundance.

The normalized quadratic restricted profit function described in (3) satisfies the conditions required for it to represent the underlying production technology. The function is linearly homogeneous in prices. Symmetry in cross-price terms is obtained by defining the matrix A to be symmetric. The restricted profit function satisfies convexity in variable quantity prices globally (and locally) whenever the A matrix is positive semi-definite.

Instead of estimating the restricted profit function in (3) it is more convenient to estimate the system of four variable quantity equations, one for each of output and the three variable inputs (fuel, labor, and gear/equipment), obtained from (3) by using Hotelling's Lemma. These equations are formulated in actual quantities, therefore, all four equations must be estimated to obtain the parameters of interest. (Space limitations preclude inclusion of these equations.)

If convexity is rejected by the data, it can be imposed by a re-parameterization of the

A matrix (Wiley, Schmidt, and Bramble, 1973). This re-paramaterization uses the product of a matrix D and its transpose to replace the A matrix, ie., $A = DD^T$. The D matrix is a lower triangular matrix with zeroes in the first column. While it is still possible to obtain separate elasticity estimates for each pair of inputs, the re-paramaterization requires a nonlinear estimation technique. A new set of equations are estimated using a nonlinear maximum likelihood procedure since the a_{ik} parameters are replaced by the appropriate combinations of d parameters from the D matrix. The correspondence between the a_{ik} and d parameters is as follows: $a_{ll} = d_1^2$, $a_{lf} = d_1d_2$, $a_{lg} = d_1d_4$, $a_{ff} = d_2^2 + d_3^2$, $a_{fg} = d_3d_5 + d_2d_4$, and $a_{gg} = d_4^2 + d_5^2 + d_6^2$.

Zellner's (1962) iterative SUR technique is used on the systems of equations to estimate the parameters for each of the four vessel types. The number of observations is: seine (21), gillnet (80), troll (84), and gillnet-troll (60). Resulting parameters are checked for acceptance of convexity in prices. Troll sample estimates are consistent with this characteristic, however, the seine, gillnet, and gillnet-troll samples do not accept convexity.[5] As discussed above these samples are re-estimated using maximum likelihood with a system of nonlinear equations.[6] Space limitations preclude reporting parameter and elasticity estimates for all four samples, however, Table 1 reports parameter estimates and their standard errors for two samples, the seine and the gillnet-troll. These samples are representative of the range of elasticity responses over the four vessel types.

Results

Table 2 reports estimated elasticities between input pairs for the seine and gillnet-troll samples. These elasticities are calculated using parameter estimates from the nonlinear estimation procedure and mean values from each sample for the regressors. The signs and magnitudes of these elasticities can be used to examine the effectiveness of input controls in preventing rent dissipation. Direct substitution takes place when, in the face of a restriction on tonnage, a fisherman tries to increase output and increases his use of inputs that are direct substitutes for tonnage, e.g., increased labor or gear. However, an indirect effect can also occur. Increased use of direct substitutes leads in turn to increased use of their complements. In this way, the employment of variable inputs that are direct complements to the restricted input also expands.

For the seine vessel, labor and gear are direct substitutes for the restricted input, while fuel is a complement. The elasticity values are large and significant for the fuel and gear inputs. The direct substitution effect means that rent dissipation occurs as seine vessel-owners substitute toward the use of increased amounts of gear and labor inputs. The indirect effect of the increased use of labor means an increased use of fuel, its complement. Since gear and fuel are substitutes, however, the net impact depends upon the relative strength of the sets of elasticities. Nonetheless, the results are suggestive of rent dissipation by seine vessels. This finding accords with Pearse's (1982) observations and Dupont's (1990) rent estimates and is of concern since seine vessels form only 8% of the salmon fleet, but take 38 % of the total fish landed (in 1982).

Results for the gillnet-troll sample (Table 2) suggest that all three variable inputs are complements for tonnage. Furthermore, the elasticity values are large and significantly different from zero in 2 out of 3 cases. Thus, there is no direct substitution effect; the indirect effect is also absent. These results support the hypothesis that tonnage restrictions on the gillnet-troll vessel are succesful.

Elasticities, not reported in this paper, for the other two vessel types show that the troll vessel is strikingly similar to the seine vessel, while gillnet-troll results represent the gillnet vessel well. Thus, the British Columbia limited entry program with tonnage restrictions per vessel appears to have been moderately successful in preventing only two of the four vessel types from dissipating resource rent in the salmon industry. Unfortunately, these vessels take the smaller share, 38%, of the total landed catch. Therefore, the program cannot be said to have preventing rent dissipation from taking place on a large scale. Based upon the findings in this paper, fisheries regulators should reconsider the use of input control programs and plan to replace them with individual transferable vessel quotas or royalty taxes.[7]

Conclusions

The paper's approach and findings may be useful to regulators of other fisheries or industries. By adopting the methodology proposed in this paper a regulator can conduct a simple review of different alternatives for input restrictions by examining the elasticities of intensity between various pairs of variable and restricted inputs. Those inputs with few substitutes or with positive or zero elasticities of intensity would be good choices for input restriction programs. Alternatively, if the regulator chooses to adopt a set of input restrictions, an examination of pairs of elasticities of intensity would help to determine the best mix of restricted inputs.

Table 1. Restricted profit function parameter estimates

	Seine		Gillnet-Troll	
Variable Name	Coefficient Value	Standard Error	Coefficient Value	Standard Error
d_1	-0.139[a]	0.060	0.128	0.111
d_2	-0.272[b]	0.151	-0.127	0.245
d_3	-0.101E-05	0.308	-0.293[a]	0.127
d_4	0.323[a]	0.106	0.591E-02	0.028
d_5	0.665E-06	0.232	0.572E-02	0.029
d_6	0.601E-07	0.124	0.145E-08	0.040
b_{tt}	3.498	2.696	-2.681[a]	1.557
b_{td}	-3.728[b]	2.283	0.458[a]	0.204
b_{dd}	-1.424[a]	0.704	0.073[b]	0.053
b_0	-3.581	3.001	-3.490	1.910
b_t	-0.418	3.040	3.038[a]	1.618
b_d	5.411[a]	1.103	-0.567[a]	0.216
c_{ys}	-0.013	0.708	0.273	0.558
c_{yt}	1.678	1.538	2.697[a]	1.267
c_{yd}	-1.670[a]	0.721	0.453[a]	0.236
c_y	1.220	1.953	-0.370	1.436
cls	0.199	0.661	-0.033	0.187
clt	1.473	1.365	-1.566a	0.569
c_{ld}	-2.413a	0.614	-0.260[a]	0.096
c_l	-2.478	1.988	0.792	0.663
c_{fs}	0.189	1.153	-0.156	0.197
c_{ft}	-1.414	2.023	-1.479[a]	0.594
c_{fd}	-2.999[a]	0.949	-0.364[a]	0.104
c_f	-1.030	2.625	1.161	0.682
c_{gs}	13.711[a]	7.744	40.551[a]	22.139
c_{gt}	19.771[a]	10.877	-80.144[b]	61.727
c_{gd}	-9.420[a]	5.979	3.279[a]	1.097
c_g	-31.171[a]	13.713	-18.401	68.517

a 5% significance [b] 10% significance

Table 2. Cross-price elasticity and elasticity of intensity estimates[a]

	Seine			Gillnet-troll		
Quantities	Labor	Fuel	Gear	Labor	Fuel	Gear
Prices						
Labor	-0.025	-0.050[c]	0.024[c]	-0.044	0.060	-0.001
	(0.021)[b]	(0.029)	(0.014)	(0.076)	(0.107)	(0.007)
Fuel	-0.055[c]	-0.111	0.055	0.078	-0.677[c]	0.009
	(0.032)	(0.123)	(0.044)	(0.140)	(0.277)	(0.025)
Gear	0.013[c]	0.025	-0.012[d]	-0.00006	0.0003	-0.4E-6
	(0.007)	(0.020)	(0.008)	(0.0003)	(0.0007)	(0.2E-5)
Restricted Input						
Tonnage	-0.010	0.336[c]	-0.425[d]	0.452[c]	0.571[d]	1.608
	(0.029)	(0.180)	(0.251)	(0.170)	(0.356)	(1.253)

[a] Elasticity estimates use means of the data.

[b] Standard errors are in parentheses. Asymptotic standard errors use the formula for the variance of a random variable that is a nonlinear function of several random variables (Kmenta, 1977).

[c] 5% significance.

[d] 10% significance.

Endnotes

1. This explains why Squires (1987a) finds large elasticities between capital and labour, eg., 0.726, and capital and fuel, eg., 2.125, when he estimates a full static equilibrium profit function. Capital's own-price elasticity is found to be -2.821. For his fishery, the conventional elasticity is appropriate.

2. Lopez (1985) shows that the function imposes homothetic output-input separability upon the harvest technology. Marginal rates of substitution between input pairs are independent of the levels of individual outputs. Data limitations impose a single output framework, therefore, this restriction is irrelevent.

3. Additional estimation reveals that the numeraire choice makes little difference to parameter estimates and even less difference to elasticity estimates.

4. Diewert and Wales (1987) show the α_j (j = s, t, d) can be set arbitrarily, for example, equal to $1/z_j'$, where z_j' is the fixed factor vector for the first observation. Likewise, the β_i (i = y, l, f, g) may be set equal to $1/p_i'$. This convention is adopted here.

5. This finding manifests itself in downward-sloping output supply functions. Squires (1987b) finds this to be the case, as well. Output aggregation is the likely cause.

6. The calculated elasticities of intensity are invariant to the imposition of convexity in prices.

7. Taxes are not without problems. Difficulties include determining the correct rate, the necessity of an annually fluctuating rate in response to stock variability, disincentive effects that encourage illegal landings, and possible distributional effects of tax incidence. In the final evaluation, taxes are not politically popular, least of all, among fishermen. On the other hand, the individual transferable vessel quota (ITVQ) is generating a great deal of interest among fisheries economists, after having been suggested more than a decade ago as a potentially useful regulatory tool (Christy, 1973; Scott, 1979). However, since the adoption of an ITVQ is tantamount to the creation of property rights, political opposition to the quota is likely to stall any move toward its adoption.

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