Multispecies Revenue Function Estimation for North Pacific Groundfish Fisheries

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May 1998

Selected Paper for the Annual Meeting
of the American Agricultural Economics Association
Salt Lake City, UT
August 2-5, 1998

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Abstract

Revenue functions for first wholesale processing are estimated for the surimi-capable factory trawl fleets operating in the Bering Sea/Aleutian Islands groundfish fisheries. Revenue functions are estimated for four species which explain over 95% of first wholesale value. Pollock is the dominant species by value share, while Pacific cod has the highest marginal revenue per ton. The empirical model results reject the hypothesis of Leontief production, while the estimated shadow values for marginal revenue per ton were highly significant. Both findings are relevant to current policy issues and practices in the North Pacific.

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Multispecies fisheries present some of the most interesting and challenging problems in modern commercial fisheries management. Fleets are highly versatile and mobile, gear is imperfectly selective, and both product markets and fishery stocks are volatile. Each of these factors contributes significantly to the multispecies management problem.

Several papers have begun to fill the knowledge gap on fisheries production technology estimation. Squires (1987a,b) was among the first to apply modern dual methods to the estimation of multiproduct technologies in New England fisheries. Other examples of this parametric approach to technology measurement include Dupont, Kirkley and Strand, and Squires and Kirkley. More recently, Thunberg *et al*. have estimated product substitution relationships in the multi-species nearshore fishery in Florida, and Campbell and Nichol have estimated the production technologies in purse seine and longline fisheries for tuna as part of considering the potential benefits of reallocations of tuna among fleets.

In contrast to the other papers noted, which typically focus at the “exvessel” or harvesting level, this paper models the production technology at first wholesale for one of the principal fleets operating off Alaska, the surimi-capable trawl fleet. This fleet consists of 23 large factory trawler operations that are distinguished by their size and versatility of production. Surimi is a fish paste made principally from pollock that is reprocessed subsequently into a variety of product forms. Other principal products produced by this fleet are two fillet product forms, three headed and gutted (H&G) product forms, roe, and meal. This fleet competes under open-access conditions with several other fleets, including a trawl fleet that produces principally H&G products, a trawl fleet that produces both H&G and fillet products (but not surimi), and a longline fleet.

Table 1 provides some information on the gross value, catches, and product mixes at first wholesale for the surimi fleet, based on data from 1994-95. Pollock represented 94% of the gross first wholesale value of $569 million for both years combined, with Yellowfin sole representing 4%, and Atka mackerel and Pacific cod accounting for approximately 1% each. Because the trawl gear used for harvest is imperfectly selective, a mix of catch comes onboard and the operations face decisions of which species in the catch to keep and process, as well as what product forms to make.

While the catch coming onboard is mixed species, given the scope of information we have it is realistic to treat the factory operations as consisting of multiple nonjoint-in-inputs, multiple product processes. That is, a ton of Pacific cod can only be made into a set of 8-10 Pacific cod products (e.g., fillets, meal, milt, etc.) Similarly, evidence from the fleet (Table 1) is that yellowfin sole can be put into three products: whole fish, kirimi, and meal. For each species in the catch, there exists a set of first wholesale production alternatives, but each process can be written as nonjoint in the fish input.[1] Thus, we model separate production processes for four species: pollock (8 product forms), Pacific cod (12), Yellowfin sole (5), and rock sole (5).[2]

The model of production at first wholesale is constructed with an eye toward addressing two questions of interest to the industry and managers. One is what the marginal value of an additional ton of a given species is. In the North Pacific, nearly all major groundfish fisheries are quota-constrained, and the policy questions facing decisionmakers such as the North Pacific Fishery Management Council are increasingly allocational in nature. In fact, the Council currently goes through an extensive “apportionment” process when it sets the Total Allowable Catches (TACs) for the major groundfish fisheries every December. The total TAC for the BSAI groundfish complex is 2.0 million metric tons (mmt), with individual TACs for over 15 named species and species groups, with the largest single species being pollock with a TAC of 1.1 mmt. Pollock is the most sought-after species, and the Council both “apportions” the pollock TAC by time of year (to slow down the race for fish typical of open-access management) and makes harvest allocations to major sectors of the industry. Naturally, one of the questions of interest in making these decisions is how much a ton of pollock or other species are “worth” to different sectors of the industry. In multiproduct operations such as is typical for North Pacific groundfish, the answer to this question lies in determining the shadow value on the species used as input to the production of a variety of first wholesale products.

The second, and related, question is whether, as is commonly assumed, it is reasonable to think of production as being Leontief; that is, output is characterized by fixed-proportions production. Commonly the gross first wholesale value of production per ton of a species will be imputed as the inner product of a product price vector and a set of fixed average product shares. This average value per ton will only be a good guide to marginal values per ton if the production technology is fixed proportions.

Furthermore, one might suspect some sensitivity of product mix to relative product prices, particularly in operations such as the surimi-capable fleet. Some inputs may naturally be complements, and largely fixed-proportions in nature: for example, meal is complementary to production of other forms, and the proportion of input that goes into meal may not vary substantially no matter what other production occurs. Product forms like fillets and H&G seem likely to be substitutes, so one might expect a responsiveness of product mix to relative prices.

The Empirical Revenue Function

The production at first wholesale is modeled using a revenue function approach, using data routinely collected from the industry. While the data presented in Table 1 are typical, for estimation purposes we have data for 1991 to 1996. They come from weekly production reports filed by each processor that describe production by species and product form, with corresponding product values and estimates of the quantity of raw fish landed. The basic unit of analysis, therefore, is a processor-week, and the models for each species capture all records in which a processor produced that species. While they are rich in detail about catch and production over time and across firms, as noted above there is no systematic information available on the use of other inputs, so we must implicitly assume these factors are roughly constant. This necessarily tempers the conclusions that may be drawn about shadow value and product substitutability. Nevertheless, the modeling exercise can help provide some broad perspective on trends in the industry, and shed light on additional data needs. We have estimated models for the entire 1991-96 period for pollock, Pacific cod, Yellowfin sole, rock sole, flounder, and flathead sole.

Our hypothesis is that each processor chooses to produce a mix of products that will maximize revenue, given the raw fish it has at its disposal. Thus, the arguments of the dual revenue function for each processor are the input quantity for the species being processed, and the prices for each prospective product it can make.

By Shephard's Lemma, partial differentiation of the revenue function with respect to each product price yields the optimal supply function for each output, with the same arguments as in the revenue function. For each of the four species, the econometric model was a system of equations comprised of the revenue function and the associated output supply equations.

In order to avoid imposing any particular form on the revenue function and supply equations, we employed a flexible functional form in estimation. The form chosen was a Generalized Leontief (Morrison 1988),

$$R^k(\mathbf{p},\mathbf{x}) = \alpha_k + \sum_i \sum_j \alpha_{ij}\, p_i^{.5}\, p_j^{.5} + \sum_i \sum_m \beta_{im}\, p_i\, x_m^{.5} + \sum_i p_i \left(\sum_m \sum_n \gamma_{mn}\, x_m^{.5}\, x_n^{.5}\right),$$

where **x** is a vector of input quantities, and **p** is a vector of output prices. This revenue function satisfies positive linear homogeneity in product prices, and symmetry is imposed in estimation.

As Table 1 indicates, the products that can be made from each species differ. For each species, we included all products that comprised more than 1% of total production. For our particular case of nonjointness in outputs, the GL revenue function for species k is

$$(1) \qquad R^k(\mathbf{p_k},x_k) = \alpha_{ik} + \sum_i \sum_j \alpha_{ijk}\, p_{ik}^{.5} p_{jk}^{.5} + \left(\sum_i \beta_{ik}\, p_{ik}\right) x_k^{.5} + \left(\sum_i p_{ik}\right)\gamma_{kk}\, x_k,$$

where x_k is the scalar input quantity of species k and $\mathbf{p_k} = (p_{1k},..p_{nk})$ is the product price vector for species k products. By Shepherd's Lemma, the corresponding product supply system is

(2) $$y_{ik} = 0.5(\sum_{j\neq i} \alpha_{ijk}\, p_{jk}^{.5})\, p_{ik}^{-.5} + \beta_{ik}\, x_k^{.5} + \gamma_{kk}\, x_k \qquad \text{for all i.}$$

We estimated (1) and n_k equations from (2) (where n_k is the number of products for species k) jointly as a system using the nonlinear systems estimator in Shazam version 6.1 (White). The number of weekly observations on production by operation varied by species, ranging from 242 for flathead sole to 5,550 for pollock.

Results

Space limitations preclude presenting all the estimation results, but the pollock results in Table 2 are typical. The products are numbered 1-8, in the same order as listed in the pollock column for Table 1. The test of model significance (H_0: all coeffs=0) was strongly rejected.

While this flexible functional form allows for substitution among product forms due to changes in relative prices, we tested for Leontief (or fixed proportions) technology among the outputs produced. The test was whether $\alpha_{ij} = 0$ for all $i \neq j$, which from (2) can be seen to imply that product expansion paths are independent of product price ratios. This hypothesis was strongly rejected for all species, and Table 3 presents test results for pollock and Pacific cod. The results suggest product mixes are sensitive to relative output prices, so the practice of calculating revenues with fixed product ratios is called into question.

One performance measure of interest is the marginal revenue per ton of landed catch, for each species. This is obtained by a dual version of Shepherd’s Lemma, through partial differentiation of the revenue function with respect to the input quantity variable. Table 3 presents these shadow values at the mean of the data for 1991-96, for all six species.

Pollock and flounder are relatively low-valued species, with marginal revenues per ton of $236 and $436, respectively. Pollock is available in vastly greater quantities, though, and represents some 94% of the 1994-95 total revenue (Table 1). Rock sole is the most valuable, with a marginal revenue per ton of $2721 in a roe fishery, while Pacific cod is next highest-valued with a marginal revenue per ton of $1740. Pacific cod is one of the most fought-after species in the North Pacific, with a wide variety of products made from cod selling in the marketplace. Yellowfin and flathead sole are intermediate-valued species, with marginal revenues per ton of $838 and $953 per ton, evaluated at the means of the data.

The standard errors listed are asymptotic estimates based on the variance-covariance matrix of the revenue function model. All of the model estimates of marginal revenue per ton of landed catch are highly significant.

To get an idea of the variability of the marginal revenues per ton, Table 4 evaluates the shadow values at means of price and landed quantity for each year separately. These are interpreted as estimates of yearly marginal revenues per landed ton of each species. Pollock marginal values range from $147-$324/mt, while the marginal values for Pacific cod range from $1188-2278/mt. Despite the disparity in unit marginal revenues, pollock is the primary target for the surimi fleet, as noted above. This fleet does have the capability to take advantage of other species when they are also present in the catching operations.

Concluding Remarks

This paper implements an empirical revenue function approach to assessing the marginal revenues associated with multiproduct groundfish processing operations in the Bering Sea/Aleutian Islands region of the North Pacific Ocean off Alaska. The processing operations of one of four major fleets operating off Alaska, the surimi-capable factory trawlers, were analyzed using weekly production report data from 1991-96. The dominant species by value is pollock, but six other species contribute to revenues: Atka mackerel, Pacific cod, yellowfin sole, flathead sole, flounder, and rock sole. The latter five of these are reported to be processed into multiple product forms, as is pollock, so revenue functions were estimated for the species with multiple product forms. The empirical revenue functions overall were highly significant, with the hypothesis of Leontief production (insensititivity of production to relative product prices) being rejected. The revenue functions also yield estimates of the marginal revenue per ton of each species, which is a performance measure of potential interest to managers in dealing with questions of resource allocation. These marginal revenue estimates were highly significant as well. The finding of non-Leontief production is also potentially significant for policy because it suggests that relative prices play a role in marginal revenues per ton, and that estimates that ignore these differences may be biased.

It is important to emphasize several significant limitations of the modelling exercise. First, because these revenue functions do not address the cost side, for which there is little systematic data, their interpretations as performance measures must be tempered. There is little information on the use of other inputs to production besides the raw fish input, so there is potential for bias in coefficient estimates to the extent that there are large variations in input uses across or within years. It seems clear that model specifications could be improved with these types of data. It would be preferable to test for separability in the fish inputs, rather than imposing the assumption *a priori*, no matter how intuitive it appears. We have not been able to address issues of technical change which may have occurred, but it is unclear to what extent the data would support such extensions. Clearly more work is needed on these and other issues to improve the policy-relevance and empirical performance of the models.

Footnotes

1. Other inputs to production, such as labor, materials, and overhead, could be joint in the different species production lines, but we have no information with which to model these inputs. Based on the observable information on production, the nonjointness assumption on the input side is plausible.

2. For the fifth species in Table 1, Atka mackerel, there was little product variability as over 95% went into surimi.

Table 1. Value Shares by Species and Principal Product Form, 1994-95.

	Species					
Product	**Atka Mackerel**	**Pacific Cod**	**Pollock**	**Rock Sole**	**Yellowfin Sole**	**All Species**
Whole fish/food	0.01[a]	0.10	0.00[b]	0.53	0.90	0.04
H&G, with roe	.[c]	.	.	0.38	0.00	0.00
H&G, West. Cut	0.01	0.02	.	0.01	0.00	0.00
H&G, East. Cut	0.01	0.12	0.00	0.02	0.00	0.00
Kirimi	.	.	.	.	0.06	0.00
Roe Only	.	0.03	0.30	.	.	0.28
Fillets w/skin&ribs	0.00	0.04	.	.	.	0.00
Fillets, no skin or ribs	.	0.54	0.02	.	.	0.02
Deep skin Fillets	.	.	0.06	.	.	0.06
Surimi	0.96	0.07	0.59	.	0.00	0.56
Fish Meal	0.01	0.06	0.03	0.07	0.04	0.03
Milt	.	0.02	.	.	.	0.00
Species % of Value/ Total Value[d]	0.01	0.01	0.94	0.00	0.04	$569,353,613

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[a] Table entries are product shares of value for each species.

[b] Product value share <0.005.

[c] No catch and production

[d] Fractions in the last row are value shares for each species.

Table 2. Revenue Function Estimation Results for Pollock.

Coefficient	Estimate (Student's t)
α_1	-7.02E+05 (-2.25)
β_1	-4.79E-02 (-5.51)
β_2	7.45E-03 (0.26)
β_3	0.13921 (2.59)
β_4	0.17092 5.95)
β_5	2.0878 25.52)
β_6	-5.67E-02 (-4.03)
β_7	0.26527 (5.90)
β_8	-4.23E-02 (-4.75)
γ_{11}	7.59E-04 (4.21)

α_{ij} coefficients: Coefficient Estimates and (Student's-t statistics)

	1	2	3	4	5	6	7	8
1	-182.07 (-0.66)							
2	1.2668 (0.65)	105.47 (4.77)						
3	-0.56527 (0.74)	-1.5372 (-5.01)	-76.923 (-1.17)					
4	0.21863 (0.65)	-0.10799 (-1.45)	0.22462 (1.61)	2.8541 (.01)				
5	0.86839 (0.67)	0.38288 (1.57)	0.65886 (1.64)	-2.3016 (-16.28)	176.29 (6.15)			
6	0.61374 (0.63)	1.4153 (7.85)	0.27492 (0.43)	2.6033 (8.85)	-6.0857 (-12.90)	2.3536 (0.26)		
7	0.8612 (0.62)	-3.2706 (-3.02)	3.8088 (1.23)	0.73963 (0.41)	5.9439 (3.71)	0.24245 (0.62)	53.558 (34.01)	
8	-1.2152 (-0.66)	0.34524 (1.88)	-2.1533 (-5.92)	1.4587 (20.63)	2.3008 (11.79)	-0.28636 (-13.16)	-0.10728 (-1.38)	1.4604 (14.54)

LR Test of H_0: $\beta = \alpha = \gamma = \mathbf{0}$: χ^2= 13922 (37 df)

Critical χ^2 (.95, 37 df) = 55.6

Table 3. Results of Hypothesis Tests for H_0: Leontief Technology

	Species	
	Pollock	**Pacific Cod**
χ^2	2754.1	538.6
D.F.	26	66
Critical χ^2	41.9	95.6

Table 4. Mean Shadow Values Per Ton of Catch Input to Processing

Species	Value ($/mt)	Std. Error	Period
Pollock	236	16.3	1991-96
Pacific Cod	1740	153.2	1991-96
Yellowfin Sole	838	15.2	1991-96
Rock Sole	2721	97.7	1991-96
Flounder	436	58.1	1991-96
Flathead Sole	953	193.7	1991-96

Table 5. Yearly Shadow Values for Pollock and Pacific Cod.

	Pollock		Pacific Cod	
Year	**Value ($/mt)**	**Std. Error**	**Value ($/mt)**	**Std. Error**
1991	324	17.7	2278	177.3
1992	302	18.9	1923	201.8
1993	147	14.7	1188	107.5
1994	153	12.0	1271	119.8
1995	213	16.7	1785	168.3
1996	231	20.7	1325	122.9
1991-1996	236	16.3	1740	153.2

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