Productivity Growth and Product Choice in Fisheries: the Case of the Alaskan pollock Fishery Revisited

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Abstract

Many fisheries worldwide have exhibited marked decreases in profitability and fish stocks during the last few decades as a result of overfishing. However, more conservative, science- and incentive-based management approaches have been practiced in the US federally managed fisheries off Alaska since the mid 1990's. The Bering Sea pollock fishery is one such fishery and remains one of the world's largest in both value and volume of landings. In 1998, with the implementation of the American Fisheries Act (AFA) this fishery was converted from a limited access fishery to a rationalized fishery in which fishing quota were allocated to cooperatives who could transfer quotas, facilitate fleet consolidation, and maximize efficiency. The changes in efficiency and productivity growth arising from the change in management regime have been the subject of several studies, a few of which have focused on the large vessels that both catch and process fish onboard (catcher-processors). In this study we modify existing approaches to account for the unique decision making process characterizing catcher-processor's production technologies. In particular, we focus on sequential decisions regarding what products to produce and the factors that influence productivity once those decisions are made using a multiproduct revenue function. The estimation procedure is based on a latent variable econometric model and departs from and advances previous studies since it deals with the mixed distribution nature of the data. Our productivity growth estimates are consistent with increasing productivity growth since rationalization of the fishery, even in light of large decreases in the pollock stock. These findings suggest that rationalizing fishery incentives can help foster improvements in economic productivity even during periods of diminished biological productivity.

Key Words: Fisheries, Revenue function, Productivity, Environmental Factors

1. Introduction

The common property characteristic of many fisheries and the nature of the regulations that have been imposed to deal with the resulting depressed fish stocks and profitability in several countries around the world have had negative consequences on the economic performance of fisheries and paradoxically on the fish stocks as well. Regulations have often been based on direct output or input constraints that are ineffective in minimizing the side effects of common-property management such as over-capitalization. When restrictions are placed on a subset of the inputs used in fishing, the regulations often induce increased use of unregulated inputs to maintain or increase fishing power and catch share, promoting the so called race-for-fish or “input stuffing”. As a consequence harvesting efficiency and profits can be severely impaired with continued pressure on fish stocks

These consequences, while ironic, have been widely discussed in the literature and several authors have stressed and measured the efficiency impacts associated with alternative types of management such as the allocation of access privileges and the use of rational incentives (Weninger and Waters 2003, Tingley and Pascoe 2005, Vestergaard 2005, Felthoven 2002, Grafton et al 2000*)*. However, there are few examples in the literature (e.g. Paul et al. 2009) that have focused on investigating the financial implications of these new types of management both in terms of enhanced revenue due to increased processing productivity as well as flexibility in the timing and coordination of fishing to support processing decisions. Specifically, the hypothesis we test in our research is whether and to what extent eliminating the race for fish has augmented processors’ abilities to control the rate at which fish enter the processing chain and provide them with greater ability to adapt their product choices in response to prices as well as other regulatory and environmental factors. We examine this hypothesis in the context of processing revenue and productivity aboard vessels that jointly conduct fishing and processing.

In line with the study performed by Paul et al., this paper focuses on the revenue patterns of the North Pacific pollock fishery which operates in the Eastern Bering Sea off Alaska. This fishery is one of the largest in the world either in terms of both volume and value (NMFS 2011) and makes an interesting study case since after the implementation of the Alaskan Fisheries Act (AFA) in 1998 it passed from an limited access fishery to a cooperative based fishery in which quota were allocated to vessel owners who could then sell or lease their quota to other vessel owners. Harvest quota were allocated to three sectors: the inshore sector (comprised of catch boats that delivered to onshore processing plants), the mothership sector (comprised of catcher boats that delivered to floating processors) and the offshore sector, the focus of this paper (comprised catcher-processor vessels).

Paul et al. analyzed production in this fishery over the time period 1994-2004 and concluded that the effects of the AFA induced better coordination between catching and in-vessel processing, better catch screening (e.g. more time to search for higher quality, more uniform fish) and handling (smaller tows and less bruising), which collectively led to a more valuable product mix. In other words, the AFA appeared to generate greater productivity and thus revenue per unit of fish caught, even when controlling for price fluctuations and changes in product composition.

One of the caveats in their modeling effort was the large number of zeros in the left-hand-side of the supply equations jointly estimated with the revenue function. Many vessels did not produce one or more of the outputs over the span of the data, such as surimi. For these vessels it was then assumed that the appropriate technology wasn't available and dummy variables were created to eliminate particular products as choices in specific observations within the dataset. While the high number of zeroes did not cause technical problems for the econometric estimation, it did raise some questions about whether there were more rigorous and holistic ways of modeling the joint decision of what products to produce and what determines the trade-offs among that chosen and the observed productivity. But these questions require technical considerations regarding the correct distribution of the data and resulting econometric specification.

Zeroes associated with a given processed product may appear in the database for several reasons, many of which may be unknown to the researcher. For example, the vessel may not have had the processing equipment onboard at some times (e.g. surimi), or nature or the environment may dictate whether or not a given product is available during that portion of the season (e.g. roe). Market prices of outputs may also play a role since unfavorable prices may induce the vessel to not process a specific product. In fact, the existence of so many zeroes for some products reflects that there is a discrete nature underlying the data generating process – to either process or not process a given type of product. This nature however is not purely discrete since once the output value appears greater than zero it can take any value within a considerably large range. This leads us to wonder whether econometric estimation methods based on mixed distributions that combine discrete and continuous features would better accommodate the nature of these data.

In this context, the present paper's goal is to build an empirical and testable econometric framework which takes into account the mixed nature of the distribution of our data. More specifically, on the theoretical side we derive a multiproduct revenue function model and on the empirical side we build a testable model based on a flexible functional form for the revenue and derived supply functions. Econometric estimations are carried out by following a two-step latent variable model approach based on Shonkwiler and Yen (1999). With the model and the empirical estimations we analyze impacts on productivity and revenue before and after implementation of the AFA, accounting for large changes in the fish stock that occurred in the post-AFA period.

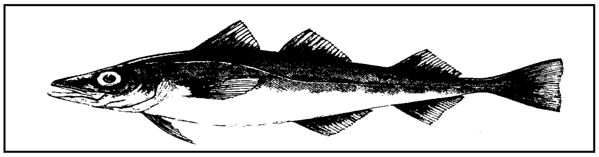
The Pollock fishery: Location, Vessels and Targeted Species

The Alaskan Pollock fishery encompasses a large area in the Bering Sea between Russia and Alaska (Figure 1). This fleet is comprised of vessels that solely catch and deliver pollock to shoreside or floating processors and other vessels that do both catching and processing (the focus of our study). The vessels are on average 100 meters long, with an average capacity 1800 gross tons, operating with 6000 horsepower on average. They all use similar trawl gear and the targeted specie is pollock, a pelagic whitefish from which the vessels produce several products.

Figure 1 – Bering Sea

Figure 2 – The Typical Vessel

Figure 3 – Alaska Pollock *(Theragra chalcogramma)*



2. The Basic Theoretical Model

The model is based on a multiproduct short-run revenue function which represents the maximum attainable revenue for a vessel given prices, fishing and processing inputs and technology, and environmental conditions. In general, the function takes the form of

$$R(\mathbf{P},\mathbf{Z},\mathbf{T}). \qquad (1)$$

Where **P** is a vector of M output prices, **Z** a vector of L input levels, and **T** a vector of J fishing conditions (weather, technological factors and fish biomass).

Assuming vessels are price taking firms[1], from (1) we can derive the conditional supply functions associated with each of the processed products using Hotelling's lemma. That is,

$$Y_m = \partial R/\partial P_m\ , \qquad (2)$$

where Y denotes the output quantity and m the specific product. R is convex in **P.** Further revenue function properties are homogeneity in **P** and non-decreasing in **P** and **Z**. Outputs can be either substitutes or complements depending on their cross-price effects. These properties are empirically testable and this model can also be used to test for the sign and magnitude of the impacts of the regulatory changes caused by the AFA imposition in 1998.

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[1] This fishery produces a majority of the world supply of pollock in most years, along with Russian stocks, but the global price of pollock is considered to be driven by the entirety of the whitefish market, which includes several other species and stocks worldwide. Thus, the price taking assumption is probably reasonable for any particular vessel or firm in this fishery.

More specifically, first-order revenue elasticities with respect to the components of the **P**, **Z**, and **T** vectors, are used as indicators of the forces underlying revenue changes:

$$\varepsilon_{RP_m} = \frac{\partial R}{\partial P_m}\frac{P_m}{R} = \frac{Y_m P_m}{R} \qquad (3)$$

They reflect the marginal revenue share of product *m*, which must be positive for the products exhibiting supply responsiveness.

The input elasticities

$$\varepsilon_{RZ_l} = \frac{\partial R}{\partial Z_l}\frac{Z_l}{R} = \frac{W_l Z_l}{R} \qquad (4)$$

where W_l is the marginal shadow value of input *l*, reflect the shadow shares. These must be positive for productive inputs. The elasticities with respect to the **T** factors,

$$\varepsilon_{RT_j} = \frac{\partial R}{\partial T_j}\frac{T_j}{R} \qquad (5)$$

similarly reflect the revenue contribution of T_j and may be either positive or negative.

Equation (5) can also be used to express (economic) productivity growth in terms of the trend in revenues not explained by other productive factors in the model. That is, $\varepsilon_{Rt} = \partial \ln R / \partial t = \frac{\partial R}{\partial t} / R$, which may also be positive or negative.

3. Data and Empirical Implementation.

The data contains weekly observations for catcher-processors in the North Pacific pollock fishery during 1994-2009 obtained from the U.S. National Marine Fisheries Service federal observer program, weekly production reports, and vessel characteristic data combined from federal, Alaska state, and U.S. Coast Guard vessel registration files. Overall the sample contains 533 observations. These data were aggregated to the seasonal level ("A" is the winter and "B", the summer) since roe an important product in the industry is rarely present in pollock in the summer and therefore practically infeasible in the B season for many years in our model.

As shown by the data, in TABLE 1 below, in this fishery, more than 90% of total revenue earned by this fleet comes from 4 processed pollock products: regular fillets (*F*), deep skin fillets (*D*), surimi (*S*) and roe (*R*). Besides theses products, vessels produce other pollock products (*O*) such as mince or meal and oil, and a small amount of other non-pollock (*N*) products (mostly flatfish and Pacific cod fillets, but this is limited to very small amounts in their allocation by fishery managers; in earnest, these vessels target pollock while fishing).

TABLE 1 – Yearly Revenue Shares (%) by Pollock Product

	Roe Pollock	*Boneless Filet*	*Deep Skin Fillets*	*Surimi*	*Other Pollock*	*Non-Pollock*
1994	23.9	9.8	5.9	49.0	7.0	4.4
1995	31.1	2.6	11.1	44.0	7.5	3.7
1996	28.6	2.7	15.9	36.9	11.4	4.4
1997	29.5	0.6	12.3	46.8	7.6	3.2
1998	17.3	13.2	16.3	39.3	7.3	6.6
1999	22.3	3.0	29.8	35.3	4.9	4.6
2000	38.3	4.2	17.7	30.4	3.7	5.8
2001	38.6	13.1	14.1	23.1	2.4	8.9
2002	33.1	18.3	13.6	25.2	2.8	7.0
2003	31.7	19.5	18.1	20.9	3.3	6.5
2004	35.2	17.8	17.6	19.0	3.2	7.2
2005	28.3	17.0	18.0	26.0	4.4	6.3
2006	23.6	22.9	16.5	22.9	5.3	8.8
2007	21.6	20.4	20.0	24.2	5.5	8.3
2008	18.7	21.1	15.1	32.7	5.2	7.1
2009	16.2	23.3	22.5	21.4	5.8	10.7

Therefore, in eq. 1, **P** includes the prices for the *M* pollock processed products. **Z** includes variables representing fishing effort and includes weekly crew size (*C*), number of days fished (*DA*), vessel characteristics (gross tonnage (*G*), length (*L*) and horsepower (*H*)) and two additional dimensions of fishing effort – towing duration (*DU*) and number of tows (*TO*). *DU* represents the actual time spent with gear in the water to obtain the observed catch. *TO* represents how many times a vessel puts the trawl gear in the water and extracts fish.

The latter two dimensions of fishing effort have changed in the post-AFA period and it is purportedly due to the regulatory change (Wilen and Richardson 2008). As the race for fish ended as a result of the AFA, vessels often take more tows screening for better quality fish of a consistent size, and the resulting hauls are often lower to discourage bruising and retain product quality. The net result is a greater number of shorter tows and heightened product value. In other words, changes in DU, TO and DA embody the regulatory impacts on revenue and product mix. **T** contains a time trend (*t*), and measures of environmental conditions that may affect revenue – a wind and storm indicator (*NPI*), and indicators of surface air temperature (*SW*) and (*SA*), average winter and average annual respectively.[2] Higher values of NPI and lower values of SW and SA are consistent with better fishing conditions. Moreover it contains a measure of fish stock (*K*) which is the estimated EBS pollock, age 3+, biomass measured in thousands of tons and represents the pollock that are annually recruited into the fishery.

As in Paul et al. 2009~~.~~, a dummy that takes the value 0 if the period pertains to season A, and 1 otherwise (D_R) is used to construct a perceived price for roe $P_R^* = P_R(1 + D_R\beta_R)$ in order to take into account the fact that roe harvesting is allowed only during season A. Another dummy (D_S) that takes value 0 if the vessel never produced surimi, 1 otherwise, is used to construct a

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[2] More details on the description of the variables can be found at Paul, Torres and Felthoven, 2009.

perceived price for surimi, $P_S^* = P_S(1 + D_S \beta_S)$ since it is assumed that a vessel does not have the technology to produce surimi if it never produced it during the time spam. β_R and β_S are parameter estimates.

For the revenue function in (1) we assume a fully flexible generalized Leontief:

$$R_{it} = R_{it}(\mathrm{P}_{it}, \mathrm{Z}_{it}, \mathrm{T}_{it}) \equiv \sum_m \sum_n \alpha_{mn} P_{mit}^{*\;.5} P_{nit}^{*\;.5} + \sum_m \sum_l \delta_{ml} P_{mit}^* Z_{lit} + \sum_m \sum_j \delta_{mj} P_{mit}^* T_{jit}$$
$$+ \sum_m P_{mit}^* (\sum_l \sum_q \delta_{lq} Z_{lit} Z_{qit} + \sum_j \sum_k \delta_{jk} T_{jit} T_{kit} + \sum_l \sum_j \delta_{lj} Z_{lit} T_{jit} \qquad , \quad (12)$$

for vessel *i* at time *t*. Subscripts *m*, *n* denote output price, *l*,*q* input levels and *j*,*k* fishing conditions. The star superscript denotes that we are using the perceived roe and surimi prices in the price vector **P**. The functional form for (2) is then derived accordingly to (12), that is

$$Y_{mit} = \frac{\partial R_{it}(\mathrm{P}_{it}^*, \mathrm{Z}_{it}, \mathrm{T}_{it})}{\partial P_{mit}^*} \equiv \sum_n \alpha_{mn} P_{nit}^{*\;.5} / P_{mit}^{*\;.5} + \sum_l \delta_{ml} Z_{lit} + \sum_j \delta_{mj} T_{jit}$$
$$+ \sum_l \sum_q \delta_{lq} Z_{lit} Z_{qit} + \sum_j \sum_k \delta_{jk} T_{jit} T_{kit} + \sum_l \sum_j \delta_{lj} Z_{lit} T_{jit} \; , \qquad (13)$$

Because regulations require that the flesh and bone left over after primary products (e.g., -regular fillets (*F*), deep skin fillets (*D*), surimi (*S*) and roe (*R*)) cannot be dumped at sea and must be made into oil, mince, or meal, we classify these are secondary products and assume production levels are not determined through the same price signals we have specified for the primary products. As a result, supply functions for these products and the very small amount of other non-pollock products are derived through Hotelling's lemma and they are modeled as leftovers or ancillary products.[3] Therefore, in eq. (13) $m = (R, F, D, S)$.

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[3] Federal "full retention and utilization" guidelines mandate that byproducts from fish processing (carcasses, flesh etc.) cannot be dumped into the sea. So mince, meal or oil made out of flesh and carcasses are produced regardless of prices observed.

4. Data and Estimation

In Paul et al. the parameters of the equation (12) are estimated jointly in a system formed by equations (12) and (13) using seemingly unrelated regression (SUR) techniques. As discussed in the introduction, the fact that there are too many zeroes indicate that data generating process may be mixed, partially discrete partially continuous. Several econometric models have been built in order to deal with this problem for single equation models, for example the double hurdle models and their variants (Blundell and Meghir (1987), Cragg (1971), Heckman (1976) and Amemya (1974)). Since we in fact have a system of censored equation we follow an alternative modeling approach based on a two-step procedure proposed originally by Heien and Wessells (1990) and later refined by Shonkwiler and Yen (1999). There are *M* outputs and *I* vessels in the sample and we consider each Y_m in (2) as a non-negative random variable with probability density function (pdf) of

$$f(y_m) = \begin{cases} f_+(y_m) & \text{if } \mathrm{y_m} > 0 \\ f_0 & \text{if } \mathrm{y_m} = 0 \end{cases} \qquad (14)$$

To model the vessel operators' processing decisions we assume they may derive benefits or positive net-revenue, by deciding to process product *m*. These benefits are represented by a pair $(Y_{1m}^{**}, Y_{2m}^{**})$ of latent benefit random variables where Y_{1m}^{**} is the one associated with the decision to process or not process product *m*, and Y_{2m}^{**} represents how much to be processed. Assuming that these variables are continuous and real-valued, a parametric bivariate model for $(Y_{1m}^{**}, Y_{2m}^{**})$ may be constructed by assigning a joint cumulative distribution (cdf),

$$F(y_1^{**}, y_2^{**}) \qquad (15)$$

In which $(Y_{1m}^{**}, Y_{2m}^{**})$ are real valued pairs of the latent variables.

Based on Shonkwiler and Yen, the first step of the modeling process may be defined as,

$$Y_{1m}^{**} = g(\mathrm{x}_{1m}^{'}\beta_{1m}) + e_{1m}$$
$$Y_{1m} = \begin{cases} 1 \text{ if } Y_{1m}^{**} > 0 \\ 0 \text{ otherwise} \end{cases} , \tag{16}$$

And the second step as

$$Y_{2m}^{**} = g(\mathrm{x}_{2m}^{'}\beta_{2m}) + e_{2m}$$
$$Y_{2m} = \begin{cases} Y_{2m}^{**} \text{ if } Y_{2m}^{**} > 0 \text{ and } Y_{1m} = 1 \\ 0 \text{ otherwise} \end{cases} \tag{17}$$

Where subscripts *i* and *t* are omitted for clarity. $g(\mathrm{x}_{1m}^{'}\beta_{1m})$ is the functional form for the equation describing the discrete decision to process or not to process product *m*, and $g(\mathrm{x}_{2m}^{'}\beta_{2m})$ is the functional form for the equation describing how much of output *m* is being processed; $\mathrm{x}_{1\mathrm{m}}$ and $\mathrm{x}_{2\mathrm{m}}$ are vectors of product specific explanatory factors and β_{1m} and β_{2m} are vectors of parameters associated with each product *m*. e_{1m} and e_{2m} are random errors.

Assuming for each product *m* that e_1 and e_2 are bivariate normally distributed with $cov(e_{1m}, e_{2m}) = \delta_m$, the conditional mean of Y_{2m} can then be defined as

$$\mathrm{E}(Y_{2m} | \mathrm{x}_{1m}, \mathrm{x}_{2m}; e_{1m} > -g(\mathrm{x}_{1m}^{'}\beta_{1m})) = g(\mathrm{x}_{2m}^{'}\beta_{2m}) + \delta_m \frac{\phi(g(\mathrm{x}_{1m}^{'}\beta_{1m}))}{\Phi(g(\mathrm{x}_{1m}^{'}\beta_{1m}))} . \tag{18}$$

In which, $\phi(g(\mathrm{x}_{1m}^{'}\beta_{1m}))$ and $\Phi(g(\mathrm{x}_{1m}^{'}\beta_{1m}))$ are respectively the normal pdf and cdf evaluated at $g(\mathrm{x}_{1m}^{'}\beta_{1m})$.

Now, given that $\mathrm{E}(Y_{2m} | \mathrm{x}_{1m}, \mathrm{x}_{2m}; e_{1m} < -g(\mathrm{x}_{1m}^{'}\beta_{1m})) = 0$, the unconditional mean of Y_{2m} is then defined as

$$\mathrm{E}(Y_{2m}|\mathrm{x}_{1m},\mathrm{x}_{2m}) = \Phi(\, g(\mathrm{x}'_{1m}\beta_{1m}))g(\mathrm{x}'_{2m}\beta_{2m}) + \delta_m \phi(\, g(\mathrm{x}'_{1m}\beta_{1m})) \; . \tag{19}$$

Given (19), Y_{2m} can be redefined as

$$Y_{2m} = \Phi(\, g(\mathrm{x}'_{1m}\beta_{1m}))g(\mathrm{x}'_{2m}\beta_{2m}) + \delta_m \phi(\, g(\mathrm{x}'_{1m}\beta_{1m})) + v_{2m} \tag{20}$$

To implement the model empirically, in the first step, probit estimates of $\beta_{1m}, \hat{\beta}_{1m}$, are calculated and then introduced into (20),

$$Y_{2m} = \Phi(\, g(\mathrm{x}'_{1m}\hat{\beta}_{1m}))g(\mathrm{x}'_{2m}\beta_{2m}) + \delta_m \phi(\, g(\mathrm{x}'_{1m}\hat{\beta}_{1m})) + v_{2m} \tag{21}$$

In a second step the M equations of the system in (21) plus the revenue equation are estimated jointly by SUR techniques. The functional forms for the revenue function and for each derived supply for product m are defined by (12) and (13). For the first step, we assume a linear functional form for $g(\mathrm{x}'_{1m}\beta_{1m})$. That is,

$$Y_{1mit} = \alpha_m + \sum_m \gamma_m P^*{}_{mit} + \sum_l \gamma_l Z_{lit} + \sum_j \gamma_j T_{jit}$$

For m = (*R, F, D, S, O, N*), l = (*C, DA, G, L, H, DU, TO*), j = (*t, NPI, SW, SA, K).*

5. Results

The Estimation and Measures

Individual parameter estimates from our models have limited intuitive content for these flexible functional forms,[4] therefore the analyses rely on first-order elasticities fitted at the sample mean and statistically tested against zero using standard errors computed by the delta method.[5] In Table 2 we present the first order elasticities, that is, the computed values for

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[4] Also due to lack space we do not present them here. They can be obtained however upon request to the corresponding author.

[5] In a future version of this will also feature standard errors calculated by the Krinsky-Robb method.

equations (3), (4) and (5), considering the whole period as well as pre-AFA and post-AFA periods.

The results indicate that the value of fish biomass had the expected positive and statistically significant impact on revenue. Considering the whole period a 1% increase in pollock fish stock increases revenue by 0.87%. This impact was substantially higher in the pre-AFA than in the post-AFA period. In earlier work (Paul et al.) the stock variable was not found to be a significant determinant in catch over that sample period and was not included in the final specification. Here, however, when utilizing the longer temporal horizon of the fishery that encompasses considerable variation in stock sizes (in particular, large stock declines in most recent years), we find stock to be a significant determinant of both catch and revenue productivity.

Moreover our measure of productivity, as given by the revenue elasticity with respect to the time trend, shows a highly statistically significant ε_{Rt} of 0.102, indicating a strong growth in economic productivity including harvesting *and* processing. This productivity residual is higher than that reported in Paul et al. due to three primary reasons. First, we have included changes in the pollock stock in this paper, which were not included in the earlier study and account for large declines in catch that in the earlier study were attributed to fishing productivity, even though the stock declines may more accurately be attributed to decreases in environmental productivity. Second, to make this paper as up to date as possible, we have included five additional years of data. Third, in this paper we have modified the model to reflect the discrete choice of product selection, which should better characterize the technology and again, affect the resulting parameter estimates. We plan to conduct more robust comparisons of the two model approaches using the same time period and stock information to analyze the extent to which the modeling innovations have affected the results.

These caveats aside, the results from both research efforts provide strong evidence that the flexibility in both harvesting and processing product choices in a rationalized fishery have substantively contributed to the economic performance of the North Pacific pollock fishery. Further, this trend is more than two times as large in the post-AFA period than in the pre-AFA years, which is particularly striking given the dramatic stock declines we have observed in the last several years in this fishery.

Looking at other revenue impact measures, the elasticities of revenue with respect to output prices are all positive (considering all 533 observations) and statistically significant considering the primary products (roe, deep and regular filets and surimi) and other pollock products. The largest estimated share is with surimi (29.4%) followed by deep skin fillets (20%), roe (19.7%) and regular fillets (11.3%). This pattern hasn't changed in general in the pre- and post-AFA periods with the exception of the result regarding the elasticity of revenue with respect to regular filets in pre-AFA period that violates the non-decreasing in prices property of a revenue function.[6]

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[6] Future research will resolve this issue.

Table 3: First Order Revenue Elasticities*

Products			**Z** Factors			**T** Factors		
Full Sample	Estimate	t-stat		Estimate	t-stat		estimate	t-stat
ε_{R,P_R^*}	**0.187**	*4.15*	ε_{R,Z_c}	**0.265**	*5.58*	$\varepsilon_{R,T_{NPI}}$	0.207	*1.54*
ε_{R,P_F}	**0.113**	*5.53*	ε_{R,Z_H}	**0.388**	*7.33*	$\varepsilon_{R,T_{SW}}$	0.086	*1.69*
ε_{R,P_D}	**0.200**	*8.52*	ε_{R,Z_L}	**-0.411**	*-4.80*	$\varepsilon_{R,T_{SA}}$	**0.312**	*3.52*
ε_{R,P_S^*}	**0.294**	*20.81*	ε_{R,Z_G}	**0.149**	*4.45*	$\varepsilon_{R,t}$	**0.102**	*7.37*
ε_{R,P_O^*}	**0.062**	*2.59*	$\varepsilon_{R,Z_{DA}}$	0.150	*1.70*	ε_{R,T_K}	**0.875**	*3.37*
ε_{R,P_N^*}	-0.010	*-0.52*	$\varepsilon_{R,Z_{TO}}$	0.058	*0.79*			
			$\varepsilon_{R,Z_{DU}}$	**0.265**	*5.87*			
Pre-AFA	estimate	t-stat		Estimate	t-stat		estimate	t-stat
ε_{R,P_R^*}	**0.199**	*4.26*	ε_{R,Z_c}	**0.197**	*2.26*	$\varepsilon_{R,T_{NPI}}$	-0.019	*-0.26*
ε_{R,P_F^*}	**-0.088**	*-2.19*	ε_{R,Z_H}	**0.583**	*5.87*	$\varepsilon_{R,T_{SW}}$	**0.529**	*4.45*
ε_{R,P_D^*}	**0.267**	*5.78*	ε_{R,Z_L}	-0.308	*-1.75*	$\varepsilon_{R,T_{SA}}$	0.112	*0.95*
ε_{R,P_S^*}	**0.436**	*19.59*	ε_{R,Z_G}	**0.219**	*3.98*	$\varepsilon_{R,t}$	0.057	*1.93*
ε_{R,P_O^*}	0.076	*1.55*	$\varepsilon_{R,Z_{DA}}$	**0.529**	*3.52*	ε_{R,T_K}	**1.863**	*4.47*
ε_{R,P_N^*}	**-0.059**	*-2.12*	$\varepsilon_{R,Z_{TO}}$	0.108	*0.70*			
			$\varepsilon_{R,Z_{DU}}$	0.077	*0.88*			
Post-AFA	Estimate	t-stat		Estimate	t-stat		estimate	t-stat
ε_{R,P_R^*}	**0.236**	*9.59*	ε_{R,Z_c}	**0.298**	*5.89*	$\varepsilon_{R,T_{NPI}}$	0.289	*1.65*
ε_{R,P_F^*}	**0.183**	*13.51*	ε_{R,Z_H}	**0.344**	*6.48*	$\varepsilon_{R,T_{SW}}$	-0.031	*-0.42*
ε_{R,P_D^*}	**0.201**	*13.09*	ε_{R,Z_L}	**-0.454**	*-5.42*	$\varepsilon_{R,T_{SA}}$	**0.371**	*3.69*
ε_{R,P_S^*}	**0.277**	*31.22*	ε_{R,Z_G}	**0.133**	*3.79*	$\varepsilon_{R,t}$	**0.117**	*4.68*
ε_{R,P_O^*}	**0.072**	*3.81*	$\varepsilon_{R,Z_{DA}}$	0.010	*0.11*	ε_{R,T_K}	**0.647**	*2.80*
ε_{R,P_N^*}	0.017	*1.06*	$\varepsilon_{R,Z_{TO}}$	0.045	*0.62*			
			$\varepsilon_{R,Z_{DU}}$	**0.333**	*7.15*			

(*)Numbers in bold mean statistically significant at 5%.

Regarding the Z vector the most important revenue factors are horsepower, crew number, and duration and gross tonnage. Number of tows and days at sea although positive, as expected, are not statistically significant at 5%. Over time we observe couple of notable changes.

Horsepower became substantially more, and crew less, important in the post-AFA. In the pre-AFA period days fished had a relative higher and statistically significant impact on revenue compared to the post-AFA period, when its elasticity became very low in magnitude and statistically not significant. This is consistent with the results found in Paul et al. 2009 and corroborates that time became less binding after the rationalization of the industry. Fishing conditions embodied in **T** do not appear to have significant impacts on revenue, *ceteris-paribus*, in particular the North Pacific Index, measured by $\varepsilon_{R,T_{NPI}}$. That is, a greater tendency toward windy and stormy weather, when considered at the seasonal level, does not appear to significantly impact revenue. Surface air temperature for the winter decreases its impact on revenue, measured by $\varepsilon_{R,T_{SW}}$, from the pre- to the post-AFA period. But annual air surface temperature featured, on the contrary, an increase in its importance to revenue gains (measured by $\varepsilon_{R,T_{SA}}$).

6. Concluding Remarks

In this article we have used a multiproduct revenue function to analyze the revenue and productivity patterns after the implementation of the American Fisheries Act (AFA) on the North Pacific Pollock fishery. This act has transformed the industry from a restricted open access fishery to a rationalized industry that can act more cooperatively with the distribution of transferable fishing quotas. In contrast to previous studies we have used a latent variable model to estimate a system of equations, some of which are censored, to take into account the mixed nature of the data. Our modeling framework allows for interactions among all arguments of the revenue function, including inputs (crew, vessel characteristics, and fishing methods) and environmental factors (weather and fish stock).

The preliminary results of the study reflect the contributions of market, technological, regulatory, and environmental factors to revenue and productivity in the industry. In particular the marginal contribution of days fished and number of tows have changed, reflecting differential fishing and processing strategies present in the pre- and post-AFA periods. . In particular, increases in these factors exhibit positive and significant marginal contributions to revenue over the whole fleet. The decrease in the marginal contribution to revenue of days at sea is consistent with the fact in the post-AFA period, time has become less binding and other dimensions of effort, such as product form and product recovery rate are more important drivers of value in the fishery..

Our productivity residual, which controls for wide range of factors affecting revenues in this fishery, is strongly positive and found to be higher in the post-AFA period that in previous studies. We attribute this difference to our explicit accounting of the contribution of fish stock sizes to catch levels and the marked decrease in the number of pollock available to the fleet in recent years. Our results thus reflect that productivity growth appears to be higher in a rationalized environment, even in the face of diminishing environmental productivity, which is a fairly striking result and display of ingenuity by the fleet.

Further research will also address the second-order effects on revenue and the effects of input levels, fishing effort and environmental indicators on input shadow values. It will also take into consideration the panel nature of the dataset, the potential for endogeneity issues regarding some measures of fishing effort, and provide more explicit tests of the way in which our modeling innovation affects our resulting estimates of productivity growth when compared to the approach used in our earlier study.

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