Determinates of Bristol Bay Sockeye Demand and Ex-Vessel Price Implications Based on Key Market-Clearing Factors

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Abstract

Fishermen, as price-taking producers in a perfectly competitive fishing market, are at the mercy of many and biological market factors that effectively determine the price they receive for their catch. In the world's largest Sockeye salmon fishery of Bristol Bay, Alaska, ex-vessel price (the price fishermen receive) has a high degree of volatility subject to market and biological conditions of the fishery. This research article highlights the significance of many different factors that affect the final ex-vessel price that fishermen in Bristol Bay, Alaska receive for their catch in order to allow for more efficient fishing production decisions. Time-series data collected predominately from the Alaska Department of Fish and Game, among other sources, is statistically analyzed using Ordinary Least Squares regression. The results obtained from the analysis suggest that salmon export markets, inputs to production, and substitute goods influence the ex-vessel price of Bristol Bay sockeye salmon.

Commercial fishing in Bristol Bay, known for "supplying half of the world's supply of Sockeye" (Knapp 2014), traces its origins back to the late 1800's. Until 1951, when motorized boats were first introduced, 25 foot sailboats using hand-pulled linen gillnets were the only legal method of harvest for Sockeye salmon (Troll 2011). Management of the Bristol Bay fishery switched from federal to state in 1959, when Alaska became a state (Knapp 2007). In 1973, the state of Alaska passed the Limited Entry Act, spawning the Commercial Fisheries Entries Commission and subsequently leading to the issuance of permits for the Bristol Bay fishery in 1975 (Apgar-Kurtz 2012). A total of 2,069 permits were issued in 1975, with a total of 1,862 permits renewed for fishing use as of 2013 (CFEC BIT Data). The objectives of limited-entry management, net (150 fathoms), and vessel length restrictions (32 feet) were to allow for sustainable biological management, increase economic benefits to the state of Alaska and assure Alaska resident participation in the fishery (Apgar-Kurtz 2012, Petterson 1983).

Although the limited-entry fishing system has allowed for sustainable fish harvest in the long-run, increased competition between producers (fishermen) creates a "race" to catch as many fish as quickly as possible in order to utilize the time allotted by the Alaska Department of Fish and Game to maximize personal harvest, and implicitly, revenue. Instrumental in the race for maximized revenues, is the price taken by fishermen (ex-vessel) from seafood processors whom buy the Sockeye for wholesale processing. Findings have supported a larger Sockeye salmon harvest leading to a decrease in equilibrium price due to a greater supply in salmon (Knapp 2004, pg. XI-1). In effect, a higher estimated run-size (and lower price expectation) incentivizes fishermen to increase the volume of fish harvested per vessel in order to maximize profits.

These profit maximization methods such as "capital stuffing" (Knapp 2007, pg. 37) are implemented by increasing vessel capacity and efficiency while adhering to the 32 foot vessel limit. A more common method is using a technique such as "power-rolling" (pulling fish caught in the net on deck to be "picked" out later by the fishermen) which leads to a decrease in fish quality due to bruising and spoiling. This "ex-vessel price expectation effect" (increasing harvest potential to alleviate low prices) influenced by management and market factors have implications for the quality of salmon sold on the market. Both of these profit maximization methods increase total fishery costs without increasing the value of the total stock, lending to a decrease in total economic rent for the fishery.

Fishery size, capital investment, and increased competition are not the only factors that lead to rent-dissipation and changes in demand, however. Since the Bristol Bay industry relies heavily on imports to Japan (McDowell 2014), ex-vessel price is subject to the strength of this market. Also, it has been agreed upon throughout the industry that Alaskan salmon prices have been affected by farmed salmon (Valderrama & Anderson 2009, pg. 116).

The primary objective of this article is to determine the demand for Bristol Bay sockeye salmon based on substitute goods, export markets, and inputs to supply. The secondary objective is to understand the marginal effects of these market factors on demand, which will allow producers and processors to better adjust to changes in salmon demand in order to smooth the "ex-vessel price expectation effect" so that ex-vessel price is less volatile.

Literature Review

Research suggests decreases in commercial fishery ex-vessel prices as a result of increased aquaculture production (Valderama & Anderson 2009). Assuming wild and farmed fish are sufficiently close substitutes (Jiang 2007), economic theory supports ex-vessel price decrease as aquaculture production increases. Additionally, certain endogenous factors associated with limited-entry fisheries may negatively affect ex-vessel pricing. These variables, amongst others, include the effects of "capital-stuffing" (Knapp 2007), common-property harvest total, average permit and vessel value, and form of processed product exported.

Valderama & Anderson (2009) derived a total cost function for Bristol Bay, Alaska to investigate the effects of over-capitalization "capital-stuffing" caused by increased fishing effort and the economic incentives for capital-stuffing that arise from vessel length restrictions (32 foot limit). Valderma & Anderson (2009), in turn found that vessel length restrictions are causal in "capital-stuffing". Additionally, it is advised that "if limited-entry regulations are not revised to address the effects of aquaculture competition…economic rents in a limited-entry program will fall sufficiently low" (Valderama & Anderson 2009, pg. 127). In effect, a limited-entry management style incentivizes fishermen to invest in capital in order to maximize potential harvest amounts. These investments increase fishermen effort and drive the harvesting of lower quality salmon, which has further implications for changes in the ex-vessel price for fish.

However, findings also show that commercial fishermen may not have to compensate for lower prices by harvesting more salmon. Changes in consumer preference, due to an increase in world farmed salmon supply have affected prices of wild salmon (Knapp, Guetttabi and Goldsmith 2013). The McDowell Group Inc. (2014) explains that these changes in led to marketing advantages and disadvantages for wild sockeye salmon producers. Although consumer preference with regards to salmon indicates indifference toward product origin (farmed or wild), the increasing prevalence of salmon allows for niche marketing strategies for wild salmon processors. Based on these findings, McDowell Group Inc. (2014) proposes that there are several possible price advantages to marketing wild salmon as a differentiated "wild" product that the Bristol Bay market could benefit from.

A successful case of product differentiation is the institution of the Copper River Fishing Cooperative (CRFC). By switching to a cooperative management style, the CRFC was able to improve both ex-vessel prices received for their sockeye salmon in addition to product quality (Jardine, Lin, and Sanchirico 2014). The research conducted by Jardine, Lin and Sanchirico (2014) includes pre- and postshock analysis of the institution of cooperative management, and may be helpful in determining the cooperative's effect on the prices of Bristol Bay sockeye salmon.

Additional research has found that market inefficiencies with regards to the Alaska sockeye fishery are due to relatively weak property rights (Anderson 2002), leading to a tragedy of the commons. Anderson (2002) furthers this assumption about weak property rights by adding that commercial fisheries are constrained in production by technology, management methods, catch variability and marginal quality of salmon product harvested. Eagle, Naylor and Smith (2003) expand on the previous assumptions by claiming aquaculture has many product advantages because of these commercial fishery limitations. Eagle, Naylor and Smith (2003) conclude that "fishery salmon will never be able to out-compete farm salmon on consistency and availability".

Gunnar Knapp (2004) found that the harvest of Bristol Bay Sockeye salmon is statistically significant in having negative implications for the ex-vessel price of Sockeye salmon. Also, the wholesale price of Coho salmon was determined to have a positive impact on the ex-vessel price of Sockeye salmon, indicating that Chilean Coho salmon is a substitute good to Sockeye salmon. The functional form used in this experiment is the log-log format. Knapp (2004) concludes in the study that "our forecasting equation may not account for all of the factors which may affect future prices".

Lastly, Lin et. al (1989) forecasted the price of farmed Atlantic salmon using simultaneous-equations approach in order find equilibrium prices and quantities by deriving supply and demand equations for farmed Atlantic salmon imported to the United States. This study concluded that farmed Atlantic salmon "is very sensitive to the world economy" (Lin et. al 1989, pg. 486) and "farmed Atlantic salmon and high-valued Pacific salmon are weak substitutes in the U.S. and the East Countries". In conclusion, Lin et. al (1989) shows that substitutes goods are not the only factors that may affect salmon pricing, but that export market economic strength and seasonality may affect price also.

This article contributes to the scholarly body of knowledge on the subject by examining potential effects that many substitute products may have on the price of salmon, across markets. It also adds to the knowledge of how management methods, price and harvest size affect permit and vessel pricing (which effect total market cost). Also, it illustrates the effects of market changes in order to show how a limited-entry commercial fishery may lead to market inefficiencies. More importantly, findings from this research will allow scholars and fishery managers to forecast market-clearing conditions in order to produce more efficient and equitable management decisions.

Economic Theoretical Foundations

As Henderson (1922) explains, "When, at the price ruling, demand exceeds supply, the price tends to rise. Conversely when supply exceeds demand the price tends to fall. Furthermore, a rise in price will tend to, sooner or later, decrease demand and increase supply." Although supply and demand analysis helps to arrive at market-clearing prices and quantities for markets, certain food markets are subject to extreme volatility in pricing and quantity supplied due to variability in consumer preference, seasonality, and substitute and complementary goods. Not only is the Bristol Bay sockeye salmon market subject to volatility, it is also influenced by biological, political and production factors that interconnect to affect price.

A convergent cobweb model is representative of the volatile nature of the Bristol Bay sockeye salmon market. It is assumed that sockeye fishermen use naive price expectations from previous seasons in order to plan current production efforts; processors determine price based on current production. In effect, the current market price adjusts to the available short run-supply of the salmon market and is determined shortly after the season (Tomek and Robinson 2003).

The Schaefer function (Clark 1990; Schaefer 1957) for an open-access fishery is denoted as:

$$\frac{dx}{dt} = F(x) - h(t), where\ t\ \geq 0$$

In this model, $x = x(t)$ denotes the size of the resource population at time t, $F(x)$ is a function representing the natural growth rate of the fish population and the rate of fish harvested $h(t)$ at time t The harvest rate, therefore, is a function of total fishing effort E and stock size x, where E and x also pertain to factors of production.

$$h = i(E, x)$$

The total harvest in Bristol Bay is determined by the difference between the total run-size and total escapement of sockeye salmon upriver. Applying the Homans and Wilen (Valderama & Anderson 2009; Homans and Wilen 1997) theory to this model, total harvest size is bound by the time fishermen are able to fish, as determined by the regulatory agency Alaska Department of Fish and Game:

$$T = \frac{1}{rE} \ln \left[\frac{F_0}{S_T}\right]$$

Total time (T) decreases as the technology parameter (r) and effort (E) increase, and is subject to the logarithmic ratio of the total initial harvest size (F_0) and the season total escapement goal (S_T). Therefore, total fishing time increases at a decreasing rate depending on total run-size and escapement goals. Due to the regulatory nature of the fishery, ex-vessel price (P_{EV}) is in effect determined by the total harvest of the fishery (amongst other factors), and is given by:

$$P_{EV} = f(H_T) \text{ where } H_T = h(t)T$$

Furthermore, for the Bristol Bay fishery, it is assumed that fishermen maximize profit as a function of ex-vessel pricing and harvest, minus the costs of crew wages, and capital. It is inferred that greater technology, i.e. newer vessels, will reflect a higher r coefficient for capital, K:

$$max\pi = P_{EV}h - (wL + rK)\ subject\ to:$$

$$h = aE^{\alpha}x^{\beta}$$

Where P_{EV} is ex-vessel pricing and h is harvest size. wL is the cost of crew wages for fishing captains and rK represent investments in boat capital. Also, it should be noted that α and β are constant positive integers equaling 1, representing constant returns to scale for Bristol Bay fishermen.

Seafood processors buying salmon from fishermen will minimize costs as a function of capital and labor costs, and are subject to fishermen production as a product of their own production since wholesale product is a function of total harvest:

$$minC\{aZ + bY\}\ s.t.\ g(K, L,, E, x)$$

Consumers purchasing the final product maximize utility by finding the optimal consumption bundle for the sockeye good subject to budget constraints:

$$maxU(x_1,) subject\ to\ p_1x_1 \leq Y$$

Together, these biological and market conditions converge to determine the market-clearing ex-vessel price and quantity of salmon supplied for Bristol Bay sockeye salmon:

$$Q_H^D = j\left(P_{EV}, P_A, P_B, Ex_J\right)\ and\ Q_H^S = k(P_{EV-1}, P_{P_{T-1}}, H_P)$$

Quantity demanded is a function of ex-vessel price (P_{EV}) that fishermen receive for their catch, the price of farmed Norwegian Atlantic salmon (P_A), the retail price of beef (P_B) in the United States per pound, and the exchange rate (Ex_J,) in the largest Sockeye consuming market (Japan) as reported by McDowell (2014).

The supply (total harvest) equation of sockeye salmon by fishermen (Q_H^S) is a function of the lagged ex-vessel price of Sockeye salmon (P_{EV-1}), the lagged price of Bristol Bay permit ($P_{P_{T-1}}$), and the average amount of horsepower per vessel(H_P). The cost of entry to the fishery is incurred by the fisherman in the year before the fisherman is able to fish in Bristol Bay; therefore in using permit price as an input to supply for sockeye, the permit price is lagged in this model.

It is assumed that the market-clearing conditions for both the supply and demand equation is equal (supply and demand equilibrium). Due to this assumption, a reduced-form price equation representing the demand for Bristol Bay sockeye is found such that:

$$P_{Ev} = g(Q_H\ , H_{T-1}, Ex_J, P_A, P_B, P_{P_{T-1}}, H_P)$$

Where ex-vessel price is a function of the current and lagged total harvest, exchange rate of Japan, the price of farmed Atlantic salmon, price of beef, lagged permit price, and average vessel horsepower. Instead of using lagged price in order to capture naïve price expectations of this year's price according to cobweb model theory, lagged harvest size is used instead. Since lagged price is a function of lagged harvest from last year's demand equation, lagged harvest is a more reliable estimator of current price.

The hypothesis is that substitute goods, export market strength, and input supplies will all significantly impact the ex-vessel price of Bristol Bay sockeye salmon. Subject to economic theory, an increase in Harvest Size and Lagged Harvest Size would lead to a negative impact on the price of sockeye salmon. An increase in the price of farmed Atlantic Salmon and Beef would positively impact the ex-vessel price of sockeye salmon due to the substitutive nature of both. If the Exchange Rate of the Yen increased, the ex-vessel price of sockeye salmon would decrease because the Yen would in turn less valuable in comparison with the U.S. dollar; purchasing power would be negatively affected. In terms of inputs to supply, an increase in Horsepower would decrease the price of sockeye salmon due to increase in capability of the vessel to harvest large amounts of sockeye at one time (leading to lower quality). Finally, an increasing Lagged Permit Price would show increases in Ex-Vessel Price due to an expectation of greater ex-vessel price.

Empirical Model

Since a single reduced-form equation was derived using the structural demand and supply equation, the equations do not have to be analyzed simultaneously. Instead, the market-clearing condition for the

Bristol Bay sockeye industry is estimated using the method of Ordinary Least Squares to estimate the single price equation. The reduced-form price equation is specified in logarithmic format in order to estimate flexibilities for ease in interpretation and nature of the fishery. The model implements time series data collected from 1984-2013. The reduced-price demand model is:

(1) $lnPev = a_1 + \alpha_1 lnHt + \alpha_2 lnlagHt + \alpha_3 lnE\square j + \alpha_4 lnPa + \alpha_5 lnPb + \alpha_6 lnlagPp + \alpha_7 lnHp + \varepsilon_i$

This includes more variables than previous models that modelled the ex-vessel price of Sockeye salmon. Knapp (2004) used the total harvest size and the price of farmed Chilean Coho salmon to examine the effect of quantity supplied and substitute goods. The model being estimated increases explanatory power for the ex-vessel price of Bristol Bay sockeye salmon by including alternate substitute goods such as beef and farmed Atlantic salmon, in addition to supply inputs and export market strength. In turn, there should be model error in the estimation, resulting in greater explanatory power for sockeye salmon price.

The model analyzed uses time series that is tested for autocorrelation using the Durbin-Watson test. Consequently, results indicating indecision regarding serial first-order autocorrelation allows correction using the Cochrane-Orcutt transformation method if deemed necessary. Tests for multicollinearity are implemented using the Variance Inflation Factor method.

Alternatively, a model estimating the effects of price on the harvest of sockeye salmon is used in order to estimate the supply of sockeye salmon. The model will include the same variables as the reduced-form price equation, but instead harvest is used as the dependent variable instead of price as in Model 1. In addition to including price on the right side of the equation, Lagged Price will be included as well in order to adhere to cobweb model theory. Model 2 is being tested for autocorrelation and multicollinearity in the same manner as in model 1 and is:

(2) $lnHt = a_1 + \alpha_1 lnPev + \alpha_2 lnlagPev + \alpha_3 lnExj + \alpha_4 lnPa + \alpha_5 lnPb + \alpha_6 lnlagPp + \alpha_7 lnHp + \varepsilon_i$

Data Description

Data extracted from the Alaska Department of Fish and Game's *Commercial Fishery Entries Commission Basic Information Table*, a compilation of fishery statistics participation and earnings, includes: total harvest by fishermen in pounds (Ht) and the average Bristol Bay permit real price of Sockeye salmon in Bristol Bay, Alaska from 1984-2013.

The Ex-Vessel Price (Pev) in Bristol Bay is from the Alaska Department of Fish and Game's (ADFG) *Commercial Operator's Annual Report* (COAR). The data is transformed to real 2013 USD using the CPI inflation rate from the Bureau of Labor Statistics.

Farmed Atlantic salmon imported from Norway represents one of the largest origins of the farmed product so consequently the price of Atlantic salmon (in 1,000 Norwegian Kroners) was collected from Statistics Norway. The Farmed Atlantic Salmon data was originally in nominal Norwegian Kroners and metric tons, so it was transformed to 2013 USD and pounds using the Purchasing Power Parity reported from the OECD and inflation rates found in the Bureau of Labor Statistics.

The Price of Beef is used in this model from the USDA ERS and represents the yearly domestic average retail beef price from 1984-2013 in cents per pound. Originally reported as nominal prices, the data was transformed to 2013 using CPI inflation rate factors from the Bureau of Labor Statistics.

The Exchange Rates for the Japanese Yen to the U.S. dollar were found using OECD Stat.Extracts website. The data spans the years 1984-2013, and is in 2013 USD. The exchange rates serve as an indicator of market strength for Bristol Bay Sockeye salmon importing countries.

Information regarding the average amount of Horsepower for each vessel fished in Bristol Bay was obtained from the Alaska *Commercial Fisheries Entries Commission*. The data includes every vessel that has taken part in the Bristol Bay fishery. This includes non-drift gillnet vessels such as barges, set net skiffs and tenders. To account for the representation of only drift gill-net vessels, the other vessel data was omitted. The sum of horsepower each year was calculated to arrive at the average horsepower per year.

Table 1. Data Description

Label	Variable Name	Source	Data Period	Data Interval	Observation Unit
P_{EV}	Ex-Vessel Price	ADFG COAR	1984-2013	Annual	2013 USD/lb.
P_A	Atlantic Salmon Price	Statistics Norway	1984-2013	Annual	2013 USD/lb.
P_B	Price of Beef	USDA ERS	1984-2013	Annual	2013 USD/lb.
Ex_J	Exchange Rate Japan	OECD	1984-2013	Annual	2013 USD
P_P	Average Permit Price	CFEC BIT	1984-2013	Annual	2013 USD
H_T	Harvest Total	CFEC BIT	1984-2013	Annual	Pounds
H_P	Horsepower	CFEC	1984-2013	Annual	1 HP unit

Table 2. Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Years	30	1998.5	8.803408	1984	2013
Pev	30	1.414333	0.8132722	0.55	4.16
Pp	30	189941.1	121371.5	25510.02	467420.7
Pb	30	467.8091	36.50507	396.0507	528.9352
Pat	30	1.651283	0.402062	1.062164	2.680176
Ht (1'000s)	30	127817.2	43963.4	50967.5	218141.3
Exj	30	123.6066	36.79963	79.707	238.623
Hp	30	318.346	41.0659	236.9784	371.354

Results and Discussion

Multicollinearity amongst the explanatory variables was tested using the Variance Inflation Factor method. Judging from the results, Horsepower showed slight collinearity in the model with a VIF of 8.21. This multicollinearity could be due to the to correlation between Harvest Size and Horsepower. The Durbin-Watson test of autocorrelation yielded results that led to indecision as to whether or not the model possesses significant autocorrelation. Refer to Table 4 for both test results. According to these results, it is concluded that the reduced-form price equations do not exhibit issues with multicollinearity and autocorrelation.

Table 4. Testing for Autocorrelation and Multicollinearity: Model 1

Variable	VIF
Horsepower	8.21
Exchange Rate Japan	4.59
Lagged Permit Price	2.93
Farmed Atlantic Salmon Price	2.91
Lagged Harvest Size	2.00
Harvest Size	1.87
Price of Beef	1.70
Durbin-Watson Test Statistic (0.85,2.14) = 1.71	

Results from OLS statistical analysis using the reduced-form price equation is outlined in Table 3. According to the estimated results, Harvest Size, Lagged Harvest Size, Exchange Rate Japan, Farmed Atlantic Salmon Price, Lagged Permit Price and Horsepower are statistically significant in explaining the Ex-Vessel Price of sockeye salmon in Bristol Bay. The Price of Beef was not found to have any statistical significance in describing the Ex-Vessel Price. Findings from this model also support the hypothesized impacts that each variable would likely have according to economic theory. Model 1 has a relatively high R^2 suggesting that the variables are significant in explaining the variance of the mean for Ex-Vessel Price.

Table 3. Model 1 Reduced-form Price Demand Estimation

Model 1 Reduced-form Price Equation			
Independent Variable	**Estimated Coefficient**	**Standard Error**	**P>|t|**
Harvest Size	-.3105669	.1298**	0.026
Lagged Harvest Size	-.300929	.1325**	0.033
Exchange Rate Japan	-.9423	.3048***	0.005
Farmed Atlantic Salmon Price	.93	.2662***	0.002
Price of Beef	.5429	.5904	0.368
Lagged Permit Price	.3274	.0794***	0.000
Horsepower	-1.903	.7571**	0.020
Intercept	19.3761	7.7622**	0.021
R^2	0.8867		
Observations	30		
Significance at α=0.01***, 0.05**, 0.1*			

In Model 1, both Harvest Size and Lagged Harvest Size are significant at the 0.05 alpha level, and direction of the coefficient sign supports economic theory. These Harvest Size findings suggest a negative impact on price with an increase Harvest Size. Holding all else constant, an increase of 10% in Harvest Size corresponds to a 3.1% decrease in Ex-Vessel Price. Holding Harvest Size constant, last year's Harvest Size would have an almost identical negative impact of 3.0% on the Ex-Vessel Price. These impacts are slightly less than the impacts found by Knapp (2004), where Knapp (2004) estimated a 10% in Harvest Size having a 5.31% decrease in Ex-Vessel Price. Both of these findings support the fact that both last year and current year Harvest Size negatively affect the current year Ex-Vessel Price of sockeye salmon.

Since Lagged Harvest size is shown to have an effect on Ex-Vessel Price, the "ex-vessel price expectation" effect (where expectations of lower harvest lead to more competition and decreased prices) seem valid in the context of this model. Holding all else constant, fishermen who expect a greater harvest (and in turn lower price) will increase effort in order to maximize benefits, although this may cost the entire fishery altogether by decreasing total value stock.

The Exchange Rate Japan shows an almost unitary negative relationship on the Ex-Vessel Price, in Model 1. This estimation supports economic theory due to the fact that as the Exchange Rate for the Yen increases against the US dollar, the Yen has less purchasing power, leading to a lower amount of salmon Japan is able to purchase. In turn, sockeye wholesalers must account for this lower purchasing power by lowering sockeye prices so the amount of sockeye harvest can be sold; in effect, decreasing Ex-Vessel Prices.

In terms of substitute goods, Price of Beef was not found to be significant in explaining Ex-Vessel Price. However, the Farmed Atlantic Salmon Price was statistically significant as a substitute good for sockeye salmon. The estimated coefficient of Farmed Atlantic Salmon is almost unitary-elastic; a 10% increase in Farmed Atlantic Salmon Price leading to a 9.3% increase in Ex-Vessel Price of sockeye salmon. These implications are substantial for Bristol Bay sockeye salmon stakeholders, since price of sockeye is contingent upon a substitute product which has seen declining costs of production as demand increases. In effect, as the marginal cost of production continues to decrease for farmed Atlantic salmon, the price of farmed Atlantic salmon decreases as well. Sockeye, being a substitute product, would decrease in price as the farmed salmon price continues to become cheaper to produce.

Horsepower and Lagged Permit Price are statistically and economically significant in explaining Ex-Vessel Price. An increase in Lagged Permit Price by 10% corresponds to an increase in Ex-Vessel Price by 3.2%, holding all else constant. This Lagged Permit Price captures an increase in demand for permits to enter the Bristol Bay fishery when there is a change in price. Horsepower on the other hand, has a relatively high negative relationship on the Ex-Vessel Price, with every 10% change in Horsepower leading to a 19% decrease in Ex-Vessel Price. This substantial marginal effect could be due to small range in variance of average Horsepower from 1984-2013, in addition to low standard deviation from the Horsepower mean.

Results from the harvest estimation (Model 2) show a relatively low significance of overall fit for the explanatory variables in the model with a R^2 of 0.5493 (Table 5). The statistically significant variables in this model are Ex-Vessel Sockeye Price, Exchange Rate Japan, and Lagged Permit Price. No significance was estimated for Horsepower on Harvest Size, as an increase in Horsepower should significantly increase the Harvest Size according to economic theory.

Multicollinearity is not a substantial problem in the model (Table 6), and the Durbin-Watson test statistic falls within the indecision region referring to uncertainty of autocorrelation in Model 2.

Table 6. Testing for Autocorrelation and Multicollinearity: Model 2

Variable	VIF
Horsepower	9.92
Lagged Ex-Vessel Price	5.36
Exchange Rate Japan	5.25
Ex-Vessel Price	5.21
Lagged Permit Price	3.71
Farmed Atlantic Salmon Price	3.54
Price of Beef	1.62
Durbin-Watson Test Statistic (0.85,2.14) = 1.26	

Table 5. Model 2 Reduced-form Harvest Estimation

Model 2 Harvest Reduced-form Equation			
Independent Variable	**Estimated Coefficient**	**Standard Error**	**P>|t|**
Ex-Vessel Sockeye Price	-.8356	.2465***	0.003
Lagged Ex-Vessel Sockeye Price	-.1006	.2510	0.692
Exchange Rate Japan	-1.2890	.4907**	0.015
Farmed Atlantic Salmon Price	.6534	.4422	0.154
Price of Beef	1.4070	.8667	0.119
Lagged Permit Price	.3593	.1346**	0.014
Horsepower	2.4407	1.2532*	0.064
Intercept	25.7704	12.0229	0.043
R^2	0.5493		
Observations	30		
Significance at α=0.01***, 0.05**, 0.1*			

The estimated affect that Ex-Vessel Price has on Harvest Size in Model 2 conforms to supply and demand theory; as the Ex-Vessel price decreases by 10%, the Harvest Size decreases by an almost unitary 8.3%. However, since Ex-Vessel Price is determined after the Harvest Size has been determined, this estimation does not suggest causality, but correlation. When applying these results to the cobweb model, Lagged Permit Price does not affect the Harvest Size, suggesting that supply and demand in the sockeye industry may not be subject to the cobweb model when using Harvest Size as the explained variable.

Exchange Rate Japan was also significant in Model 2, but is not in compliance with economic theory. The fact that there is a decrease in Harvest Size with an increase in the Exchange Rate does not make sense, since the production of sockeye salmon is not determined by the Exchange Rate. These findings could however suggest correlation between years of low Harvest Size and high Japanese Exchange rates, but this is highly unlikely due to biological factors determining Harvest Size. The results in Model 1 better explain Exchange Rate impacts to the market.

Lagged Permit Price was also significant in explaining Ex-Vessel Price, but does not align with the parameters outlined in the economic model. An increase in last year's Permit Price should not cause an increase in Harvest Size, because it was shown to increase Ex-Vessel Price in Model 1. Consequently, an increase in Harvest Size should decrease Ex-Vessel Price (as shown in Model 1), which would in turn decrease the Permit Price.

The findings from Model 1 support the results also found in previous literature, indicating that substitute goods, export market strength, and inputs to supply all impact the Ex-Vessel Price of sockeye salmon. These results are similar to Knapp (2004) in regards to how farmed salmon is a substitute for sockeye salmon, and how Harvest Size has a negative relationship with Ex-Vessel Price. Results regarding the Exchange Rate of Japan show that the Yen impacts the Ex-Vessel Price of sockeye salmon. In regards to supply inputs, findings on Horsepower support Valderama & Anderson (2009) which suggest "capital-stuffing" having a negative effect on the Ex-Vessel Price of sockeye salmon, possibly from a decrease in quality due to increased marginal capacity for vessel production. The findings from this analysis provide further support for previous research and increase the amount of information available to the scholarly body of knowledge on this subject.

Conclusions

The most important findings of this analysis are the effects that Harvest Size, Farmed Atlantic Salmon Price and Horsepower have on the Ex-Vessel Price of sockeye salmon. The only variable that was not significant in the model was beef; more investigation as to why a substantial (theoretical) substitute good was not significant in impacting price of sockeye salmon needs to be examined. In terms of examining "capital-stuffing", it is clear that an increase in Horsepower of a vessel has a negative impact on the price of sockeye salmon; however, it is not clear in this research as to whether or not that negative impact is causal because of a decrease in salmon quality, as originally hypothesized. The total fishery cost equation estimated in Valderama & Anderson (2009) provides a more substantial insight into the effects of "capital-stuffing". With regards to the "ex-vessel price expectation effect" it is clear that an expectation of a higher harvest (based on lagged harvest) negatively impacts the ex-vessel price of sockeye salmon. Again, it is unclear as to whether or not the harvest of last year is correlated with the current year's harvest, or if last year's harvest is incentivizing fishermen to increase production (disregarding quality of fish in the process) leading to a lower ex-vessel price.

The policy implication to this analysis lead to the conclusion that a marketability of sockeye salmon needs to be increased in order to compete with decreasing farmed Atlantic salmon prices and larger harvests. Additionally, expansion in regards to finding more exporting channels for the processed good is important so as to alleviate the negative impacts that large exporting markets may have on the demand for sockeye salmon (exchange rate of Japan). Additionally, management methods need to be examined in order to determine how negative effects arising from limited-entry methods (capital-stuffing) so that the total economic rent of the fishery is sustainable into the future (as also suggested by Valderama and Anderson). Ultimately, the Bristol Bay fishery has been successful in sustainability of total fish stock; however, enhanced marketing management methods need to be implemented in order to ensure strong economic sustainability so that the *value* of the total stock of Bristol Bay sockeye salmon never not decreases.

This research could be improved by finding more observations to analyze statistically (especially on the supply side), this could have been done with more time and a greater budget. Although this research suggests as to how the fishery may be affected by "capital-stuffing" and the "ex-vessel price expectation effect", it is not clear as to whether or not these model parameters are causal in doing so. In the future, important factors that need to be included to provide more robust explanatory power of the Bristol Bay sockeye salmon market include the forms of salmon product exported, quality of product, percentages of product sold to each market, hull type, time allowed to fish, and a larger time span for observations. Adding these variables and increasing the time-span will provide a more powerful explanation of the demand of sockeye salmon in addition to the costs associated with the limited-entry management style of the fishery.

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Appendix

Figure 1. Effect of harvest size on ex-vessel price

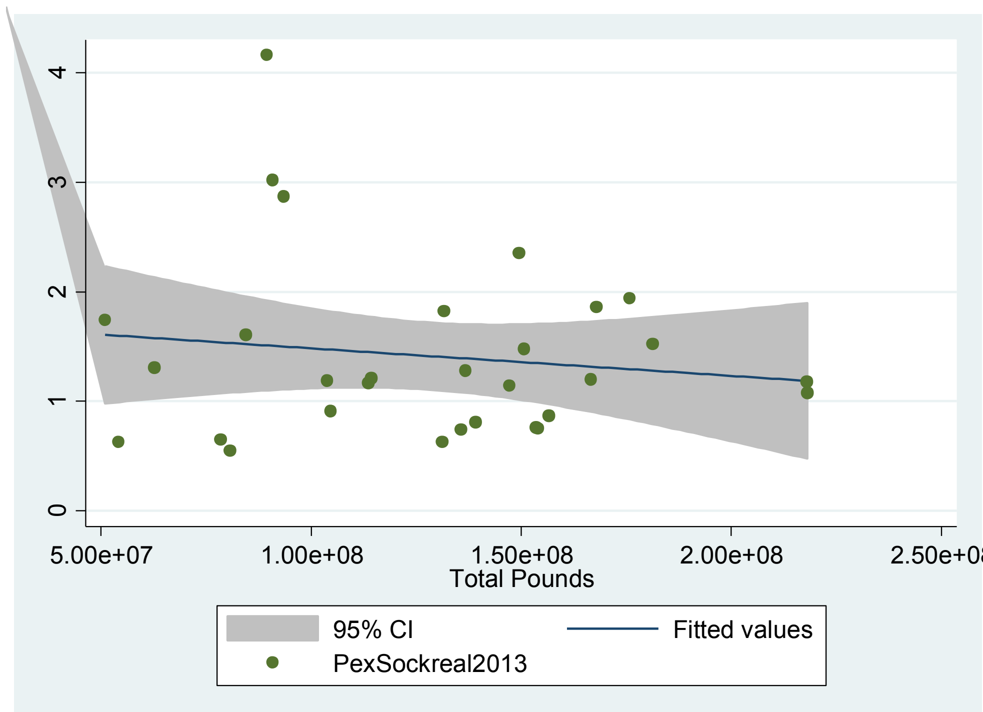

Figure 2. Effect of lagged harvest size on ex-vessel price

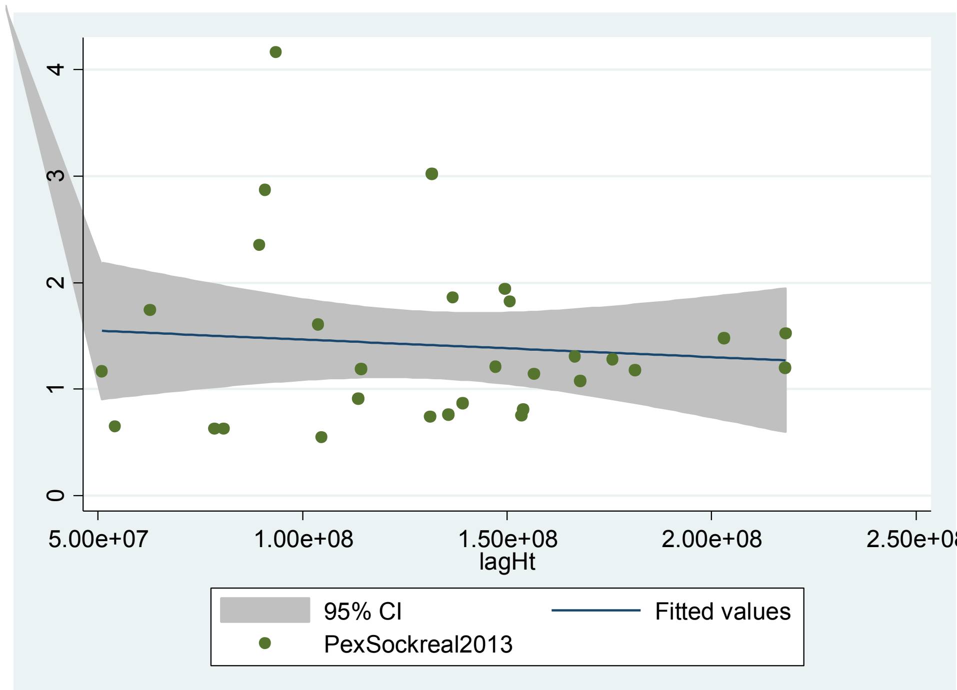

Figure 3. Effect of exchange rate japan on ex-vessel price

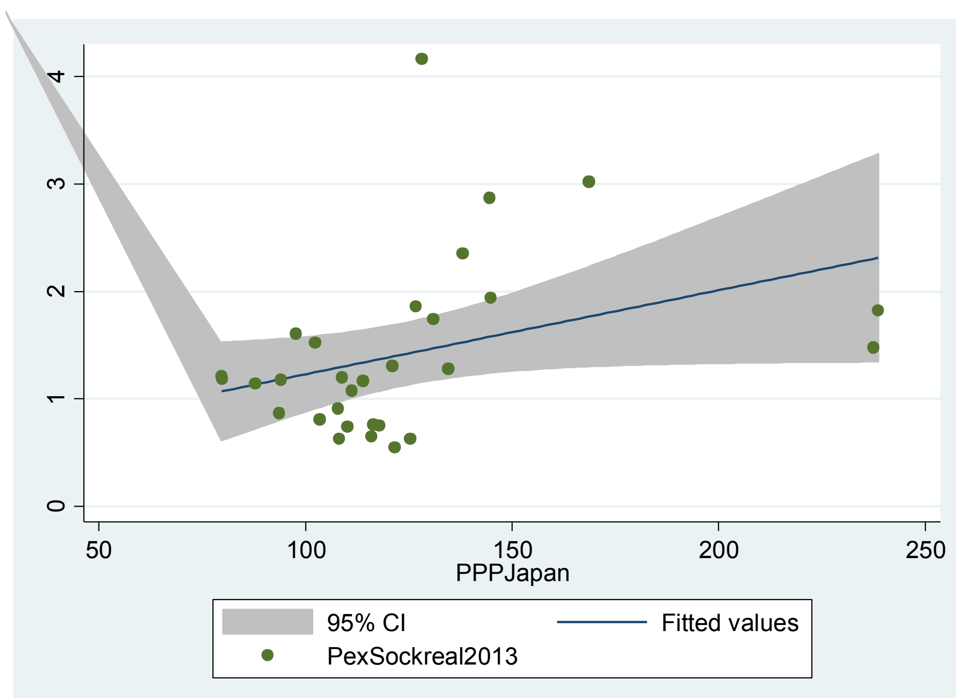

Figure 4. Effect of farmed Atlantic salmon price on ex-vessel price

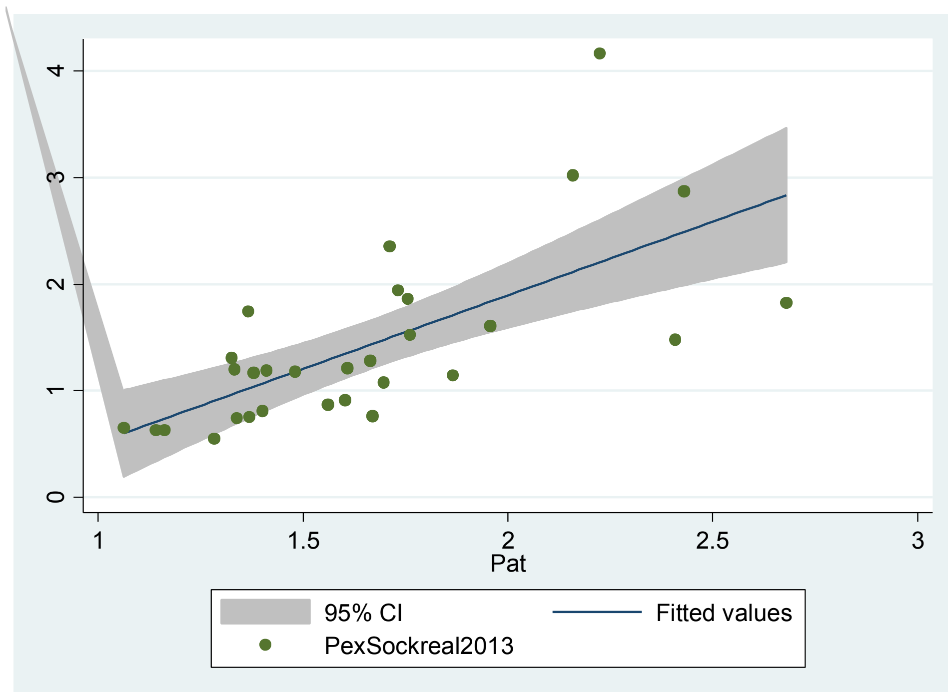

Figure 5. Effect of price of beef on ex-vessel price

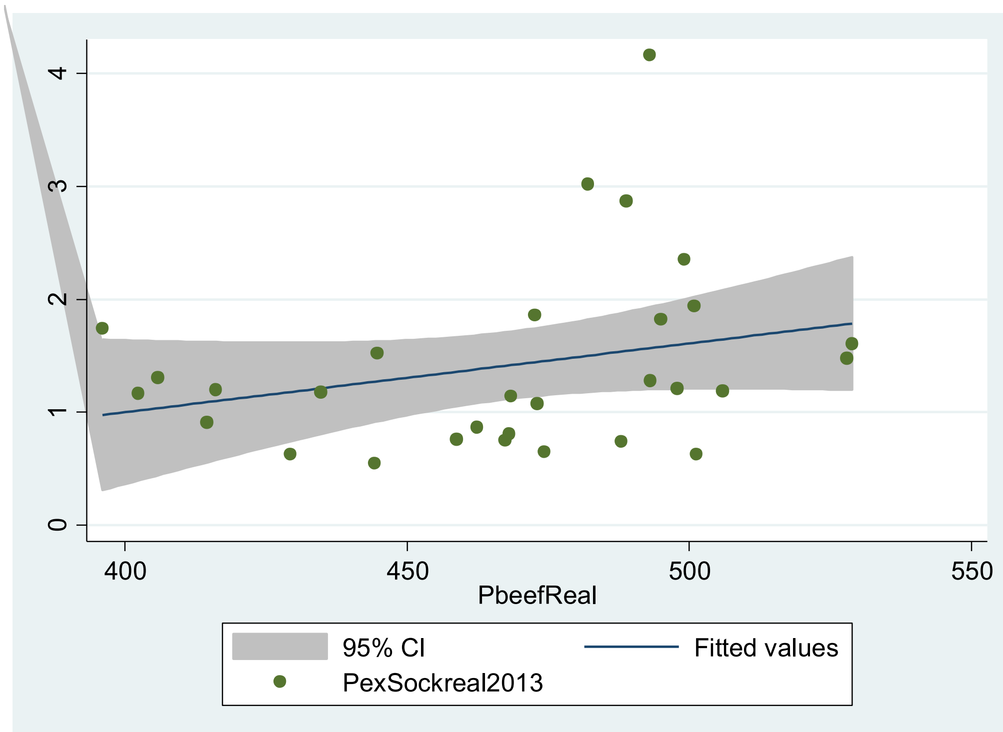

Figure 6. Effect of lagged permit price on ex-vessel price

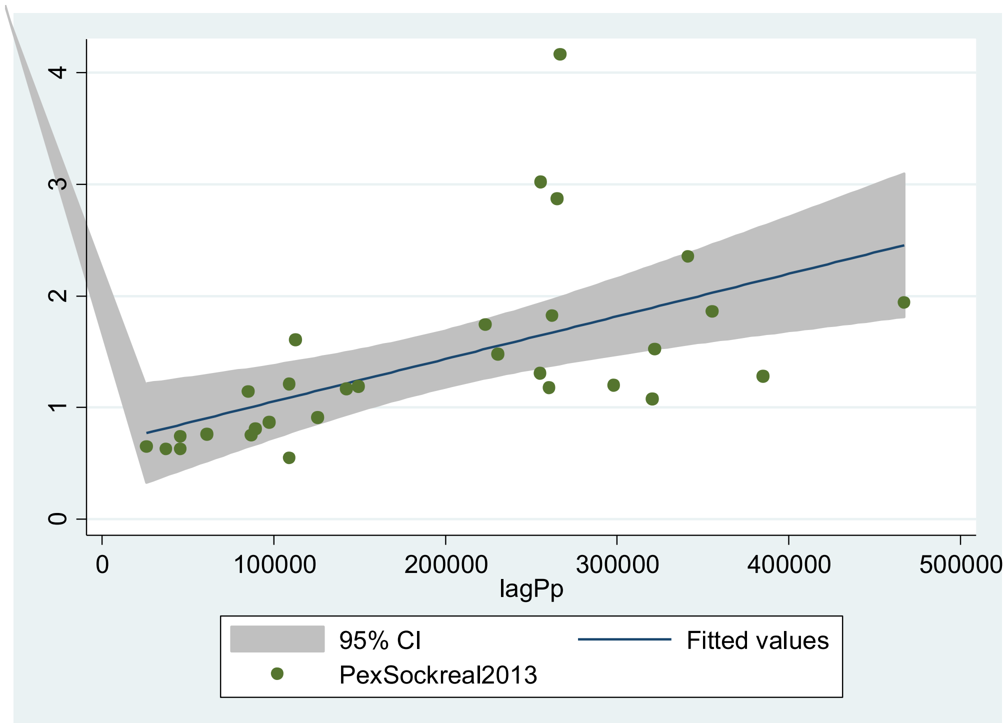

Figure 7. Effect of horsepower on ex-vessel price

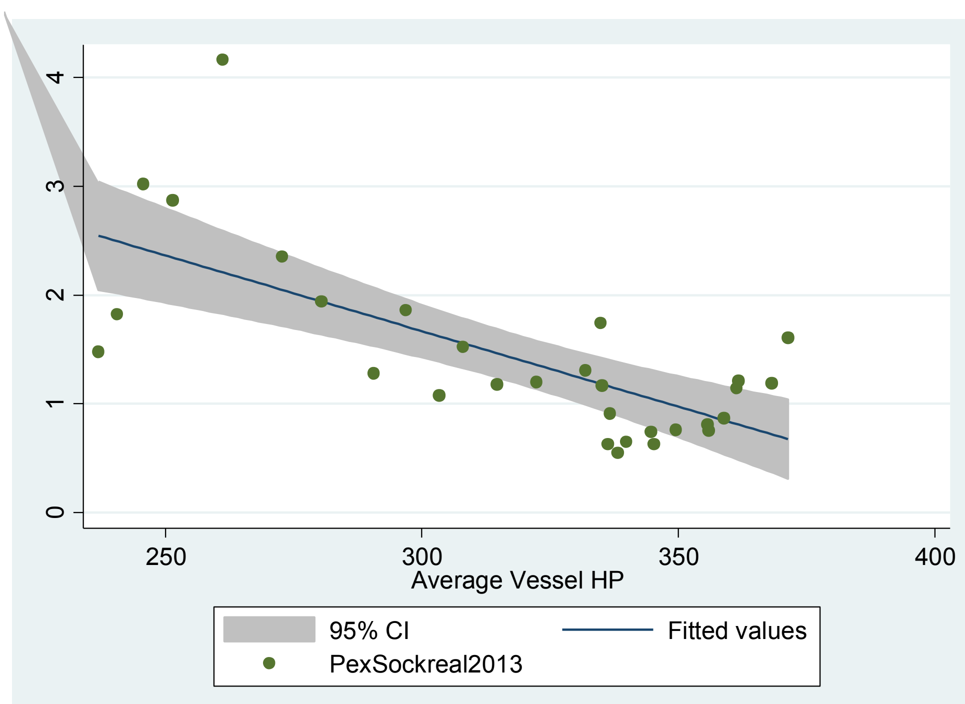

Table 7. Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
lnHt	30	18.602	0.37965	17.7467	19.2007
lnlagHt	30	18.631	0.3854	17.7467	19.2006
lnPev	30	0.2166	0.50289	-0.5978	1.42552
laglnPev	30	0.2125	0.5012	-0.5978	1.42552
lnHp	30	5.7545	0.13659	5.46797	5.91716
lnexj	30	4.7829	0.2537	4.3783	5.4748
lnlagPp	30	11.933	0.77766	10.1468	13.055
lnPat	30	0.4749	0.23134	0.06031	0.98588
lnPb	30	6.145	0.07975	5.98154	6.27087

Table 8. Correlation Matrix

	lnPev	lnHt	lnlaght	lnexj	lnPat	lnPb	lnlagpp	lnHp
lnPev	1.0000							
lnHt	-0.0178	1.0000						
lnlagHt	0.0588	0.6155	1.0000					
lnexj	0.3931	-0.0769	0.0338	1.0000				
lnPat	0.7470	0.2201	0.3275	0.5370	1.0000			
lnPb	0.2488	0.2744	0.1528	0.2007	0.4707	1.0000		
lnlagPp	0.7967	0.4226	0.4534	0.3402	0.6429	-0.1546	1.0000	
lnHp	-0.7081	-0.1217	-0.1579	0.8377	-0.7248	-0.3045	-0.6278	1.0000
lnHt	lnPev	laglnPev	lnPev	lnexj	lnPat	lnPb	lnlagpp	lnhp
lnHt	1.0000							
lnPev	-0.0178	1.0000						
laglnPe	0.1333	0.8371	1.0000	0.0000				
lnexj	-0.0769	0.3931	0.3609	1.0000				
lnPat	0.2201	0.7470	0.6049	0.5370	1.0000			
lnPb	0.2744	0.2488	0.1962	0.2007	0.4707	1.0000		
lnlagPp	0.4226	0.7967	0.8443	0.3402	0.6429	-0.1546	1.0000	
lnHp	-0.1217	-0.7081	-0.6902	0.8377	-0.7248	-0.3045	-0.6278	1.0000

Table 9. Data

Years	Ex-Vessel Price	Beef Price	Atlantic Salmon Price	Diesel Price
1983	1.43			
1984	1.48	528.0	2.408605142	2.556024832
1985	1.82	495.0	2.680175612	2.52
1986	3.02	482.0	2.158642226	2.48
1987	2.87	488.8	2.430435522	1.83
1988	4.16	493.0	2.224865836	1.84
1989	2.35	499.1	1.711260909	1.72
1990	1.94	500.9	1.731784873	1.78
1991	1.28	493.2	1.663313961	2.00
1992	1.86	472.6	1.756484384	1.88
1993	1.08	473.1	1.696493931	1.78
1994	1.52	444.7	1.761615949	1.75
1995	1.18	434.6	1.48128621	1.70
1996	1.2	416.1	1.332510802	1.65
1997	1.31	405.7	1.325288594	1.79
1998	1.74	396.1	1.366135572	1.71
1999	1.17	402.4	1.379361287	1.46
2000	0.91	414.5	1.602623873	1.52
2001	0.55	444.3	1.28207629	1.97
2002	0.63	429.3	1.161615737	1.82
2003	0.65	474.3	1.062163603	1.67
2004	0.63	501.3	1.139903236	1.86
2005	0.74	488.0	1.338575278	2.16
2006	0.76	458.8	1.669435403	2.78
2007	0.75	467.3	1.369786539	3.04
2008	0.81	468.1	1.401094453	3.12
2009	0.87	462.4	1.560924008	4.16
2010	1.14	468.4	1.866501862	2.64
2011	1.21	497.9	1.607975458	3.10
2012	1.19	505.9	1.410526401	3.91
2013	1.61	528.9	1.95701473	3.97
Source	CFEC	USDAERS	Statisticnorway	EIA

Meat Consumption	Sockeye Consumption	Permit Price	Non-Res. Earnings	Total Catch (lbs)
	0.5	230448.05	205815	203,061,950
48	0.6	262115.86	115286	150749716
49	0.5	255436.48	127273	131523714.0
49	0.5	264850.43	138665	90843592.0
47	0.4	266869.06	135328	93467610.0
47	0.3	341472.03	179493	89363878.0
44	0.3	467420.71	181757	149463505.0
43	0.4	385052.79	177461	175816338.0
43	0.5	355421.91	90615.5	136778225.0
43	0.5	320461.16	161021	167911352.0
42	0.4	321786.97	124997	218141286.0
43	0.4	260465.42	147135	181240957.0
44	0.5	298074.9	138100	218001719.0
44	0.5	255079.75	102933	166621575.0
43	0.4	223232.32	43884.5	62586918.0
43	0.3	142203.81	44000.3	50967505.0
44	0.3	125427.63	70329	113553577.0
44	0.3	108902.66	50767.6	104655388.0
43	0.4	45644.313	27227.4	80634776.0
44	0.5	25510.022	27815	54164418.0
42	0.4	37095.87	33785.1	78461500.0
43	0.3	45629.481	57395.7	131219518.0
42	0.4	61072.188	66407.7	135,574,162
43	0.2	86665.551	75258.1	153,516,693
42	0.3	89227.138	75108.1	153,885,221
40	0.1	97163.247	73758.6	139,115,944
40	0.2	85022.784	91746.4	156,527,143
39	0.2	109077.07	95919.4	147,221,522
37	0.2	149029.35	89402.1	114,296,985
37	0.2	112422.95	79095.8	103,847,415
36	0.4	100400	85685	84,362,868
FAOstat	NFMS FUS	CFEC	CFEC	CFEC

ExJapan	ExUK	Pre-Season Harvest Estimate	Actual Harvest (1,000s of fish)
237.477	0.66	27117	45813
237.554	0.752	31133	41084
238.623	0.779	35028	36629
168.519	0.682	24275	23850
144.622	0.612	16785	27501
128.135	0.562	28302	23251
137.974	0.611	28900	44026
144.796	0.563	25397	47582
134.496	0.567	29946	42232
126.673	0.57	37207	45058
111.176	0.666	41812	52103
102.229	0.653	52405	50334
94.065	0.634	55070	60734
108.817	0.641	43366	36688
120.997	0.611	33595	19020
130.895	0.604	29778	18350
113.888	0.618	24900	39372
107.835	0.661	33416	28266
121.484	0.694	24291	22167
125.255	0.667	16762	16778
115.936	0.612	24060	26384
108.147	0.546	46606	41720
110.133	0.55	32836	39269
116.354	0.543	32730	43044
117.755	0.5	34440	44451
103.388	0.546	40290	40445
93.572	0.641	33777	40448
87.761	0.647	39764	40191
79.707	0.624	38496	30335
79.814	0.631	32299	30027
97.598	0.64	25093	24169
OECD		Annual Management Reports	

Lbs/Fish	Non-Res. Permits	Average Vessel HP	Vessels Fished	CPI Inflation Rates
4.43240892	753			103.9
3.66930474	767	236.9784	1,668	107.6
3.59069901	776	240.621	1,839	109.6
3.80895564	779	245.715	1,814	113.6
3.39869859	785	251.4024	1,762	118.3
3.84344235	804	261.1665	1,832	124
3.39489177	830	272.7695	1,909	130.7
3.69501782	839	280.4069	1,885	136.2
3.23873425	856	290.6466	1,927	140.3
3.72656026	877	296.8967	1,937	144.5
4.18673178	903	303.3895	1,936	148.2
3.60076602	906	308	1,928	152.4
3.58945103	916	314.5775	1,986	156.9
4.5415824	928	322.3937	1,966	160.5
3.29058454	935	331.9171	1,941	163
2.77752071	938	334.85	1,887	166.6
2.88412011	961	335.1251	1,870	172.2
3.7025185	950	336.7106	1,859	177.1
3.63760437	931	338.1709	1,732	179.9
3.22830004	924	336.2682	1,443	184
2.97382884	940	339.915	1,553	188.9
3.14524252	949	345.1862	1,488	195.3
3.45244753	960	344.6884	1,460	201.6
3.5665062	962	349.5647	1,477	207.3
3.46190684	978	355.8606	1,463	215.303
3.43963269	976	355.655	1,458	214.537
3.86983641	995	358.8859	1,420	218.056
3.663047	993	361.3747	1,465	224.939
3.76782545	1,006	361.657	1,490	229.594
3.45846788	1,010	368.2344	1,489	232.957
3.49054028	1,003	371.354	1,469	
	CFEC Vessel DATABASE Spreadsheets			http://www.usinflationcalculator.com/

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. graph twoway (lfitci Pev Pat) (scatter Pev Pat)
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