SABLEFISH AFTER THE INDIVIDUAL FISHING QUOTA PROGRAM: AN INTERNATIONAL ECONOMIC MARKET MODEL

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A

THESIS

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Abstract

Sablefish (*Anoplopoma fimbria*) are distributed from Baja California to western Japan. Alaska is the world's principal supplier of sablefish with the majority of commercial landings occurring in the Gulf of Alaska and the Aleutian Islands. This demersal, long-lived fish is harvested in one of Alaska's highest valued commercial fisheries, primarily with fixed gear. The total value of the sablefish fishery is comparable to that of the Pacific halibut fishery, which is managed under the similar programs such as the federal Individual Fishing Quota (IFQ) program and various state programs. Although sablefish came to be managed under IFQs at the same time as halibut, the outcomes of IFQ implementation in this fishery have not received as much as attention as in the halibut fishery. Even twenty years after IFQ implementation, there is little published research on the impacts of IFQs on prices and revenues for sablefish. In this thesis project, I have described the various sablefish fisheries within Alaska and the international market conditions. A simultaneous equation market model for sablefish is developed to examine linkages between harvests, prices and revenues. The model is then used to examine the Alaska exvessel price and revenue effects that result from changes in landings, changes resulting from the implementation of the IFQs and changes to the Japanese economy.

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Chapter 1 Introduction

This thesis is organized as follows. Chapter 1 includes an introduction into the sablefish fishery and lists research objectives. The project is described in its entirety in Chapter 2, which has been formatted for submission to an academic journal. Chapter 3 includes discussion of where additional research might be performed in the area of expanding the market model to a bioeconomic model. Appendix 2 contains details about sablefish management beyond what is contained in Chapter 2.

Not Cod, It's Black Cod

Originally known as black cod, its common name was changed to the more marketable "sablefish" in the 1930s to distinguish it from the various cod species (Funk and Bracken 1984). Sablefish (*Anoplopoma fimbria*) is not related to the cod family, but the black cod name remains a regional name in Alaska. The first commercial fishing efforts for sablefish were incidental to the halibut fishery in the early 1900s. Fishing efforts drastically increased during WWII, when sablefish were valued for their high omega-3 fish oil content as supplement pills for the troops. A substantial commercial fishery didn't develop until the 1960s when Japanese longline vessels exploited stocks (Green et al. 2014). Today, both ex-vessel and export prices have been extraordinarily high for sablefish, making it one of the more valuable fisheries in terms of revenue. Most of the sablefish from United States and British Columbia waters is exported to Japan, which consumes the same amount of seafood as the U.S. despite one-third of the population (FAO 2012). Recently, sablefish has been showing up in high-end domestic restaurants as a delicacy.

Sablefish inhabit the Pacific Ocean from northern Mexico to the Aleutian Chain in Western Alaska. Stocks are highly mobile and demersal, preferring gullies and the continental shelf. Initially, sablefish was harvested in Washington and British Columbia and the commercial fishery expanded south to Oregon and California and north to Alaska (Hanselman et al. 2014). There are two sablefish stocks that differ in growth rate, size, and maturity. The Alaskan stock extends from the tip of the Aleutian Islands to Northern British Columbia and is centered in the Gulf of Alaska (Green et al. 2014). The southern stock inhabits British Columbia, Washington, Oregon and California waters. Historically, limitations on fishing seasons and harvest levels have been the primary tools to prevent overfishing (Green et al. 2014). Currently, sablefish biomass have been lower than the historical average due to low recruitment rates, but stock assessments predict an upward trend in the near future (Hanselman et. al 2014).

The fishery is managed in four regions across Alaska and assessed as a single area due to the high movement of sablefish. In 1983, the season was 12 months and by 1994, the opening was for a mere 14 days, in response to increased fishing pressures. In 1995, halibut and sablefish underwent a rationalization program implementing Individual Fishing Quotas. The IFQ program is a catch share fishery that issued quota shares to fishermen based on their landings from 1988-1990 (Hanselman et. al 2014). Since implementation, the number of longline vessels decreased from 616 in 1995 to 331 in 2013 (Fissel et. al 2014). The season increased to eight months, drastically decreasing at-sea mortality for fishermen (Sigler and Lunsford 2001). During the 14 day derby, harvested sablefish flooded the markets causing processors to become backed up and prices dropped from the influx. The IFQ program has also increased the Catch per Unit Effort (CPUE) for fishermen, reducing resources used to catch sablefish. According to Sigler and Lunsford (2001), the rationalization also decreased the harvest of immature fish, which improves the overall fish population.

The IFQ program for halibut and sablefish has been in effect since 1995. The program has been considered one of the most effective rationalization programs in Alaska and the Alaska sablefish fishery has been certified by the Marine Stewardship Council as a "well managed and sustainable fishery" starting in 2006 (Fissel et. al 2014). There have been substantial research done on halibut (and crab) demand and supply models in regards to their rationalization programs, but not as much on sablefish.

Research Objectives

This study provides an econometric model that links harvest levels with their impact on exvessel prices and revenues, import prices and quantities, and teases out the impact of changes in the regulation and management of sablefish. Model simulations are used to examine the effects to exvessel price and revenue of (1) changes in sablefish production, (2) season elongation through the IFQ program and (3) changes in the Japanese economy and exchange rates.

These simulations will be important to examine several current issues. First, current sablefish harvests are at historical low levels, similar to those of the mid-1980s. It is possible that stocks could rebound. Sablefish recruitment has high annual variability and while it's currently in a decline, it is anticipated to reach higher levels in the next few years (Hanselman et al. 2014). The health of the current fishery may be linked to the IFQ management of 1995. The resulting season elongation has been linked to many benefits for the fishing industry. Fishermen have more time to harvest their quota share or catch limits, leading to less immature fish and safer fishing conditions. Longer seasons lead to a more stable supply of fish year-round which is often reflected in higher prices and revenues. For fishermen, a longer slower season can also lead to increased bargaining power in that it gives fishermen more time to seek out better prices. Finally, due to the strong linkages between the Japanese market and the Alaska supply, exploration of the impact of the Japanese market on Alaska sablefish prices and revenues is of interest.

Chapter 2 An Econometric Model of Sablefish

Introduction

Sablefish inhabit the Pacific Ocean from northern Mexico to the Aleutian Island chain in Western Alaska. Stocks are highly mobile and pelagic, preferring gullies and the continental shelf. Initially, sablefish was harvested off the coasts of Washington and British Columbia before the fishery expanded south to Oregon and California and north to Alaska (Hanselman et al. 2014). There are two sablefish stocks that differ in growth rate, size, and maturity (Green et al. 2014). The Alaskan stock extends from the tip of the Aleutian Islands to northern British Columbia and is centered in the Gulf of Alaska (Figure 1). The southern stock inhabits British Columbia, Washington, Oregon and California waters. Sablefish are long-lived (40 years is not uncommon) with 50% of the males and females sexually maturing at 5 and 6-7 years of age, respectively (Sigler and Lunsford 2001).

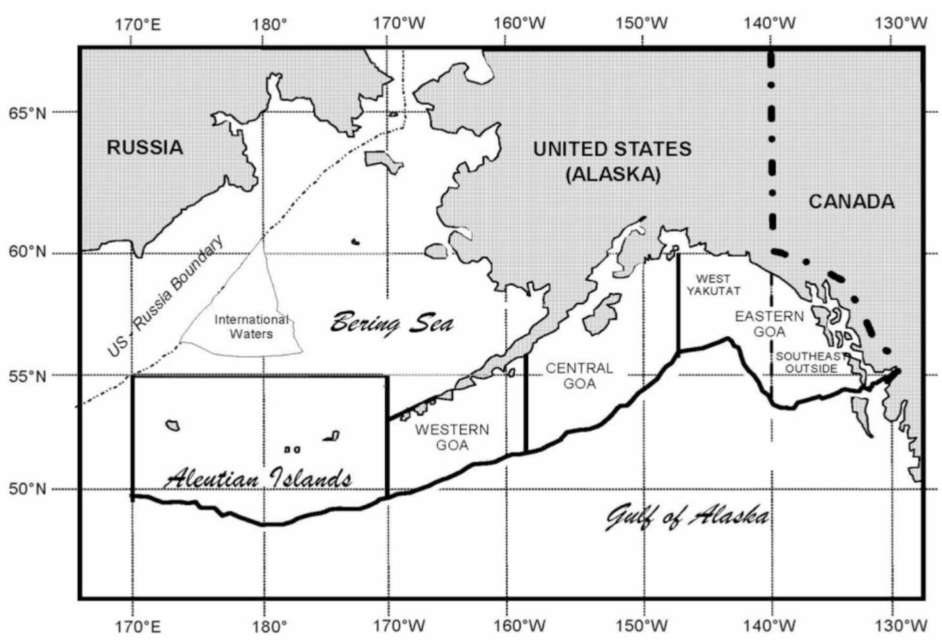

Figure 1. The federal management areas of sablefish. (Figure courtesy of Marcus Hartley, Northern Economics)

Sablefish were first caught incidentally by halibut fishermen in early 1900s. A limited commercial fishery developed during WWII, as sablefish became valued by the vitamin industry for their high omega-3 and fish oil content. However, a major commercial fishery did not develop until the 1960s when Japanese longline vessels exploited stocks (Green et al. 2014). Japanese vessels dominated the commercial harvest of sablefish in the 1960s and into the 1970s. In 1972, a record world harvest of 61.7 thousand metric tons occurred (FAO 2012). With the passage of the 1976 Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), US fishing vessels rapidly displaced the Japanese fleet, and Japan completed exited the US fishery by 1985 (Figure 2).

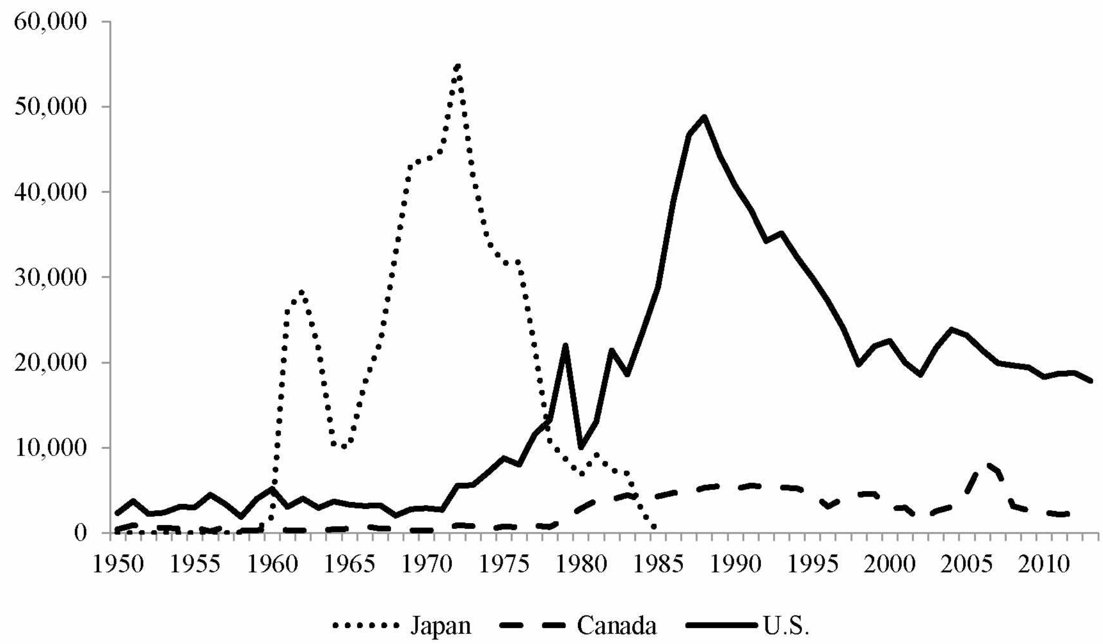

Figure 2. World landings of sablefish in metric tons (1950 to 2013).

This led to the United States supplanting Japan as the principal harvester of sablefish. Today the majority of sablefish are harvested from the continental Pacific Coast of the United States, British Columbia and Alaska (Figure 3).

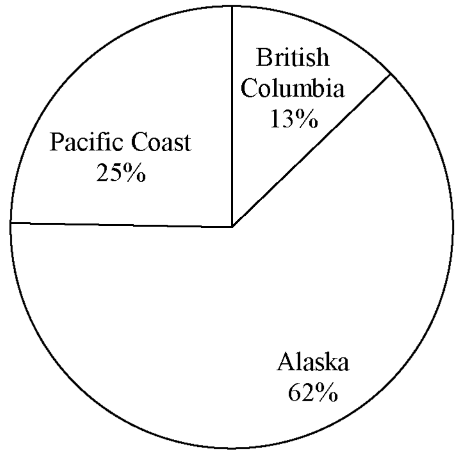

Figure 3. Percent of world landings of sablefish in Alaska, British Columbia and the Pacific Coast of the Continental United States (1988 to 2014).

While there is commercial fishing for sablefish in Washington, Oregon, and California, the larger, higher-valued sablefish fishery occurs in British Columbia, which accounts for 11% of total global harvests (FAO 2012) and Alaska, which consists of over 75% of the U.S. market share (NMFS 2013).

Since the MSFCMA was first enacted, there have been several major management changes in the Alaska commercial sablefish fishery. The first was the exit of foreign vessels by 1985, principally Japanese longliners. By the time this occurred the fishery already suffered from many of the problems that have plagued other open-access fisheries, where a race to fish leads to overfishing, overcapitalization, short seasons and reactive management strategies. The Alaska sablefish harvest peaked in 1988 at 37.3 thousand metric tons (mt) (the U.S harvest was 48.8 thousand metric tons). The North Pacific Fisheries Management Council (NPFMC) and the Alaska Department of Fish and Game (ADFG) jointly worked together to alleviate excess capital in the fishery through limited entry programs. The scientific and statistical committee (SSC) currently sets the Acceptable Biological Catch and the Overfishing Limit based on past landings and extensive stock assessments and the NPFMC then sets the Total Allowable Catch (TAC) based on the SSC recommendations. In 1995 the Alaska sablefish fishery was rationalized with the introduction of an Individual Fishing Quotas (IFQs) program that also applied to the Alaska halibut fisheries. The effect of the IFQ program to the commercial fishery was dramatic. Fleet size rapidly declined from 1,109 vessels in 1994 to 615 vessels in 1995 (Brinson & Thunberg, 2011). In 2013, 320 vessels participated in the Alaska IFQ sablefish program (Fissel et al. 2014). The IFQ program also led to season length being extended from an average of 14 days in 1994 to 245 days in 2014 (in some areas it had been as low as nine days (Sigler and Lunsford 2001)). Alaska remains the world's largest supplier of sablefish, and consistently accounts for two-thirds of world production (Fissel et al. 2014). Japan is the dominant market for sablefish, although there are other minor export markets, and a relatively small U.S. domestic market. The dominance of the Japanese market has been documented in past studies, which have identified the state of the Japanese economy, prices of competing goods in Japan as well as the dollar-yen exchange rates as principal drivers of US exvessel price (Jacobson 1982, Squires et al. 1988, Hastie 1989, and Huppert and Best 2004).

Alaska sablefish and halibut fisheries have similarities in addition to both being managed under closely related IFQ programs. They generate similar levels of exvessel revenue and are harvested at overlapping depths (150-1500 meters for sablefish, 30-300 meters for halibut). Unlike Alaskan halibut, which has several competing user groups, including sport, commercial and subsistence, the commercial fishery for sablefish is the predominant user group. While there has been substantial research evaluating the effects of IFQ program to commercial Alaskan halibut markets (Herrmann 1996, Herrmann 2000, Herrmann and Criddle 2006), there has been little effort in this area regarding the Alaska sablefish fishery. The lack of sablefish market models has limited the ability of fishery managers to quantify the economic consequences of changes in the sablefish supply, whether they are biological or management driven. This study intends to address the gap in market research for sablefish by providing an econometric model that links harvest, price and revenues. Model simulations will be employed to examine the effects to exvessel price and revenue of: (1) changes in sablefish production, (2) season elongation through the IFQ program and (3) changes in the Japanese economy and exchange rates.

The IFQ sablefish fishery has undergone substantial changes since the 1970s. In developing an economic analysis of the Alaska sablefish fishery, we have relied on several past studies of the fishery to gain insight into price formation and market structure. We have also examined past economic studies of similar fisheries, such as halibut. Alaska halibut fisheries have been the subject of numerous studies, in part because of the popularity of halibut in the US and in part, due to the size of the fishery. These studies have examined the harvest, processing and market sectors of the fisheries and the fisheries performance under IFQ management. In comparison, the available economic literature on the Alaska sablefish fishery is limited. Low and Marasco (1979), Jacobson (1982), Squires et al. (1988), Hastie (1989) and Huppert and Best (2004) are studies that have examined price formation in Alaska sablefish markets. There is scant research (and virtually no recent research) covering the time period after the implementation of the IFQ program with Huppert and Best (2004) being one of the most thorough. The lack of current economic modeling for sablefish is problematic in understanding the current Alaska sablefish market, evaluating its economic performance and the success of current management.

Low and Marasco (1979) developed a quantitative analysis for fishery management by outlining economic considerations and their impacts on the biology of sablefish. Generally, they concluded that fixed gear should be given priority over trawl fisheries for several reasons; they fished deeper with higher catch rates of mature sablefish (immature sablefish are distributed in shallower depths and they are sold for less), had less incidental bycatch of other species, and the Japanese had success with their longline fishery. Fixed gear vessels continue to have a much larger quota share than trawl vessels in the current Alaska fishery (Hanselman et. al 2014).

In order to examine the effects of the foreign vessel reduction and increased demand for sablefish, Jacobson (1982) used annual data from 1971 to 1980 to estimate a single-equation model regressing the Tokyo wholesale sablefish price on the quantity of sablefish traded in the Tokyo wholesale market, income and the real price of chum salmon. Chum salmon was chosen as a substitute because it was used at the time similarly by consumers in fish stews. The model failed to identify a statistically significant relationship between wholesale price and quantity sold on the market and the author concluded that sablefish prices were largely determined by nominal income and the prices of other goods. One of Jacobson's predictions was that increased production of chum salmon as the result of hatcheries would have a negative impact on export prices for sablefish. There is no evidence that this has happened probably due to the changing nature of sablefish consumption. During the time of his research, the U.S. was working to eliminate foreign fishing vessels, while anticipating their absence to be equally filled by domestic vessels. Due to the long-term changes, this model is not as relevant as it was when Japanese vessels were still fishing in U.S. waters. The market model also suffered from lack of data.

Squires et al. (1988) examined what the future post-MFMCA market for sablefish might look like with the advent of a U.S. controlled harvest sector that relies on Japan as the dominant sablefish market. Using monthly data from 1981 to 1986 they modeled price transmissions between the Tokyo central wholesale markets and the Alaska and Pacific Coast (California, Oregon, and Washington) exvessel prices. They found that the Tokyo wholesale sablefish market, and the Alaska fixed gear markets, are well integrated. Squires et al. also found that Alaska sablefish exvessel prices are sensitive to the volatility of the yen-dollar exchange rate. This was not found for Pacific Coast prices, which were instead dependent on local market conditions.

Hastie (1989) expanded on Jacobson's Tokyo Wholesale Model substituting real GNP for nominal GNP and using quarterly data from 1972 to 1987. In this model, quantity sold in the Japanese wholesale markets became significant and the responsiveness of price to changes in quantity was estimated to have increased between 1972 to 1980 and 1980 to 1987 time periods. In addition, Hastie (1989) reported the results of an export market model based on monthly U.S. export data from 1981 to 1987. He modeled export price as a function of Tokyo wholesale price, exchange rates and inflation. He also used separate models to describe Alaska exvessel markets and West Coast markets as a function of lagged exvessel and Tokyo wholesale prices and exchange rates. He concluded that the Japanese market largely sets Alaska sablefish exvessel prices and, in contrast to Squires et al. (1988), that this influence extends to West Coast exvessel prices.

Huppert and Best (2004) constructed two Japanese sablefish demand models of the interaction between sablefish market prices and supply to examine whether sablefish farming would be profitable in British Columbia. First, they assumed that total Japanese exports were a direct function of the Total Allowable Catch (TAC) in North America (i.e., exports only varied with quota). The first model regressed the Tokyo sablefish wholesale prices on sablefish imports, income, and the price of sockeye salmon. In the second model, Tokyo sablefish wholesale prices were regressed on sablefish imports, exchange rates and Japan's Gross Domestic Product (GDP). Exvessel price equations for Alaska, the Pacific Coast and British Columbia were specified where exvessel prices were represented as a function of Tokyo wholesale prices and an interaction term that was intended to capture shifts in exvessel price formation that occurred following the 1994 adoption of an IFQ system. The models were estimated using three-stage least squares (3SLS) for the 1987-2003 time period. Stochastic simulations were used to estimate price sensitivity to increased levels of supply. Model results indicated that sablefish exvessel prices were sensitive to exported quantities to Japan in all three fisheries (Alaska, British Columbia and the Pacific Coast), with British Columbia prices being the most sensitive followed closely by those of Alaska, with the Pacific Coast a distant third. The authors concluded that sablefish farming could be profitable up to a level of 27 to 48 thousand mt per year and would depress exvessel prices for wild harvests. In the ten years since that study was completed, sablefish farming has not grown into a substantial supply source and may be unlikely to do so.

In this study, we develop an econometric model of sablefish markets based on data that includes the twenty years since IFQ management was adopted. The market model approach has been successfully used to examine the influence of IFQ management on short term halibut revenue and prices in the Alaska and British Columbia halibut fisheries. Herrmann (1996 and 2000) developed market models of Pacific halibut fisheries in British Columbia and Alaska, which are both managed under IFQ programs (British Columbia in 1991 and Alaska in 1995). Model results showed that the elongated seasons that followed IFQ implementation substantially improved the commercial halibut revenues of each country. Herrmann and Criddle (2006) further examined the effects of IFQs in the Alaska halibut fisheries and found that nearly all the revenue-generated benefits of the program flowed to harvesters rather than processors. This outcome was also encountered in an earlier study by Matulich and Clark (2003) using a different modeling approach. This paper offers an important addition to the literature by evaluating whether a similar distribution of IFQ benefits has occurred in the Alaska sablefish fishery.

Model Specification

The market model is constructed to focus on Alaska sablefish exvessel price formation. Since 1985 the United States and British Columbia accounted for virtually the entire world supply of sablefish (sablefish are found only in the North Pacific and historically other countries accounting for sablefish landings were fishing in U.S. waters before the MSFMCA.) Alaska has been the dominant supply source, with 63% of landings, followed by British Columbia (13%), Oregon (10%), California (8%) and Washington (6%) (see figure 3). The majority of the U.S. catch is exported to Japan (85% of all U.S. exports since 1988). Based on trade data, trade publications and past academic studies it is apparent that the Japanese consumer market is the principal driver of North American exvessel prices. Japan has consistently paid a price premium for its imported sablefish and presumably this reflects its preference for more valuable large, high quality Alaska and British Columbia fish. Smaller, less valuable sablefish from Washington, Oregon and California fill demand in the other smaller markets (including the domestic U.S. market). U.S. sablefish export price to all other countries from 1988-2013 averaged 36% less than the average export price to Japan. The two sets of prices track closely (r = 0.93) indicating that the prices are closely correlated.

Given the characteristics of the world sablefish market of a dominant supplier (Alaska) and a dominate consumer market (Japan), the market model focuses on the sablefish price formation being determined largely by the Japanese market and Alaska landings. The model is represented by three behavioral equations and two market clearing identities; five endogenous variables and five equations.

The behavioral equations are: (1) the Japanese import demand for sablefish from the United States, (2) the allocation of Alaska sablefish harvest to Japan; and, (3) the exvessel derived demand for Alaska sablefish.

Japan Import Demand $$QIJUC = f_1(PIJUYR, JINCRC, PMEATR) \quad (1)$$

U.S. Export Allocation $$QIJU = f_2(PIJUR, LAN). \quad (2)$$

Alaska Derived Exvessel Demand $$PEXR = f_3(PIJUR, DLAN) \quad (3)$$

The market clearing identities are: (4) real import price in Japan and (5) Japanese per-capita import demand for U.S. sablefish.

PIJUR = [(PIJUYR * JCPI)*USYEN]/UPPI (4)

QIJUC = QIJU/JPOP (5)

Variable definitions and sources are listed in Tables 1 and 2.

Table 1. Market model variable definitions (Sources are listed in Table 2).

DLAN	Daily Alaska sablefish landings (DLAN = LAN/SLEN)
JCPI	Japanese consumer price index[a]
JINC	Japanese consumption expenditure[b]
JINCRC	Real per-capita Japanese consumption expenditure (JINCRC = JINC/(JCPI*JPOP))
JPOP	Japanese population[c]
LAN	Alaska sablefish landings (kg)[d]
PEX	Alaska sablefish exvessel price ($/kg.)[d]
PEXR	Real Alaska sablefish exvessel price (PEXR = PEX/UPPI)
PEXREV	Alaska sablefish exvessel revenue (PEXREV = PEX*LAN)
PIJU	Japanese import price of sablefish ($/kg.) (PIJU=PIJUY/(USYEN))
PIJUR	Real Japanese import price of sablefish (PIJUR = PIJU/UPPIF)
PIJUY	Japanese import price of sablefish (¥/kg.)[e]
PIJUYR	Real Japanese import price of sablefish (PIJUYR = PIJUY/JCPI)
PMEAT	Japanese consumer price index for meat[a]
PMEATR	Real Japanese consumer price index for meat (PMEATR = PMEAT/JCPI)
QIJU	Quantity of sablefish imported into Japan from the United States[e]
QIJUC	per-capita quantity of sablefish imported into Japan from the United States (QIJUC = QIJU/JPOP)
SLEN	Sablefish season length[f]
UPPI	U.S. producer price index for intermediate foods and feed[c]
USYEN	U.S. – Yen exchange rate ($/¥)[c]

Table 2. Market model variable sources

(a)	*Consumer Price Index.* Various Issues. Statistics Bureau, Ministry of International Affairs.
(b)	*Family Income and Expenditure Survey.* Various Issues. Statistics Bureau, Ministry of International Affairs.
(c)	Economagic. http://www.economagic.com. 2015.
(d)	NOAA Office of Science and Technology. National Marine Fisheries Service. *Commercial Fisheries Statistics. http://www.st.nmfs.noaa.gov/commercial-fisheries/commercial-landings/annual-landings/index*
(e)	Ministry of Finance. *Trade Statistics of Japan.* Commodity by Country. http://www.customs.go.jp/toukei/info/tsdl_e.htm
(f)	National Oceanic and Atmospheric Administration (NOAA)

The Japanese per-capita import demand for U.S. sablefish (QIJUC) (equation 1) is hypothesized to be a function of the real import price (PIJUYR), Japanese income (JINCRC), as represented by real per-capita Japanese consumption expenditure, and the real price level of meat (PMEATR). Given its strong position in the international sablefish market by Japanese markets and Alaska landings, it is intuitive that the world's price of sablefish is then set by the Japanese demand and the Alaska supply. Other suppliers, British Columbia and the U.S. Pacific Coast, have exvessel prices highly correlated with Alaska exvessel price. For example, from 1988-2013, the correlation coefficients between the U.S. and Canadian import prices into Japan is 0.95 and between the Alaska exvessel prices and those of British Columbia (r = 0.87) and the Pacific Coast (r = 0.96).

For this study, the Japanese CPI for meat (PMEATR) is included in the model as a substitute good. Meat was chosen for several reasons. Japan imports approximately half of its meat products and it relies on similar import percentages for seafood (Nagata 2008). Sablefish consumption has changed from primarily being consumed as specialty winter stews (for its rich oil content) to steaks or other quality dishes. Pacific cod and Alaskan pollock are more popular ingredients for soup dishes in winter because they are less expensive (Asakawa 2014). Using high oil content salmon such as chum salmon or sockeye that were included in historical sablefish market studies (Jacobson 1982, Hastie 1989 and Huppert and Best 2004) is not relevant to analyses that extends to the current market. Sablefish is often sold as kirimi (half of steak cut) at supermarkets for home grilling. It is also marinated, smoked, and sautéed. Sablefish is not popular in sushi or sashimi dishes due to risk of parasites in the raw fish (Asakawa 2014). The most commonly mentioned sablefish substitute in the literature is Patagonian toothfish (*Dissostichus eleginoides*), better known as Chilean seabass or in Japan, mero (Asakawa 2014, Huppert and Best

2004, Sonu 2000). However, a complete time series of toothfish prices in Japan during the modeled time period is unavailable. Because there is no general consensus or statistical evidence of another fish (except toothfish) whose changes in price may significantly affect the price of sablefish, and the focus of the paper is not to find a competing fish species, the general price index for meat was used. Using the generic price of meat as a substitute for a particular modeled fish species has been used effectively in other studies such as Herrmann (1996), Herrmann (2000) and Herrmann and Criddle (2006).

Japan is far and away the most important sablefish market and Alaska's allocation to Japan (equation 2) is largely determined by Alaska landings (LAN) that result from management quotas and the real import price (PIJUR) that Japan is willing to pay for sablefish. The price is included as an explanatory variable to account for the fact that, although exports to Japan are largely determined by landings, other minor export markets and also the domestic market exist, giving Alaskan fishermen the opportunity shift sales into and out of those markets depending on price differentials.

In the derived Alaska sablefish exvessel inverse demand function (equation 3), exvessel price (PEXR) is represented as being determined by the real export price to Japan (PIJUR) and average daily landings (DLAN). The exvessel price of Alaska sablefish is modeled as a mark-down from the Japanese sablefish real import price. This important link between Japanese and Alaska prices has been predominately mentioned in trade magazines and statistically demonstrated in past academic studies (H.M. Johnson and Associates 1998, Hastie 1989, and Huppert and Best 2004). The correlation between the Japanese import price and Alaska exvessel price (in U.S. dollars) from 1988 to 2014 is 0.88.

Although a price shift resulting from IFQs was not found in the Japanese sablefish market, it was hypothesized (and found) to have significantly influenced the derived exvessel demand. Even without price increases on the primary market, there are still price and revenue advantages to fishermen from an individual quota program. As noted in Huppert and Best (2004), a distinct effect of an IFQ is to increase fishermen's bargaining power. They note that "as a more 'rational' management of the [sablefish] fishery has become the norm in Canada and Alaska, the spread between the ex-vessel price and Tokyo wholesale price has narrowed (p. 4)." By using daily average landings (DLAN = LAN/SLEN) instead of season length alone one can estimate how daily catch effects the ability for fishermen to better bargain for higher prices. Their market power is greatest when landings are low and seasons are long. Just as landings have been decreasing the change in the season length pre- and post-IFQ has dramatically increased (figure 4). In 1994 the Alaska sablefish industry was just 14 days, in 1995, the first year the fishery was prosecuted under the IFQ the season was 235 days long. Since 1995 the season has averaged 238 days.

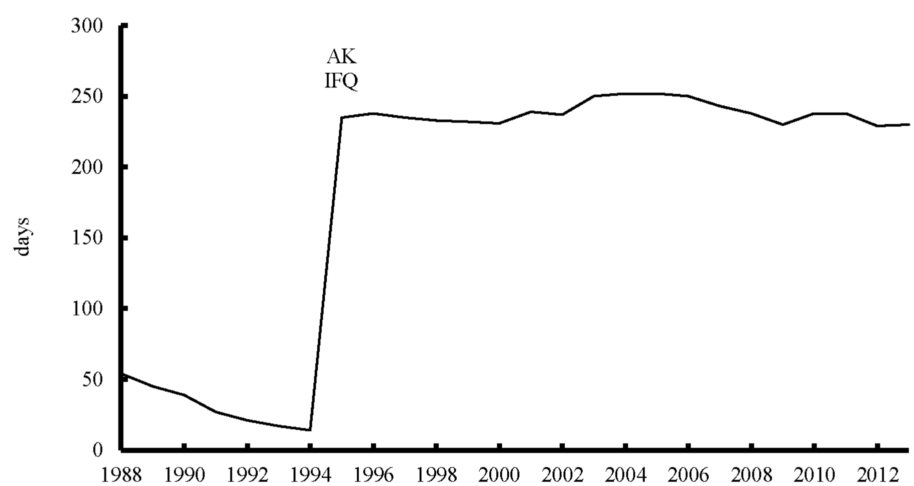

Figure 4. Commercial fishing season length in the IFQ Alaska sablefish fishery (1988-2014).

Model Estimation

The aggregate model was estimated using annual data over the sample period of 1988 to 2014. This time period coincided with both the first year that Japanese sablefish import statistics were available (following the end of the Japanese fishing vessel in U.S. waters) and the peak in U.S. landings of sablefish, which have since seen a reduction due to management decisions and ecological considerations. The equations were estimated using the three-stage least squares (3SLS) using the SAS 9.3 statistical software program (SAS 2011). The estimated coefficients, asymptotic one-tailed p-values and mean-level elasticities are presented below. The Durbin-Watson statistic (DW) was used to detect first-order serial correlation, a frequent indicator of model misspecification. In no case was the magnitude of the DW statistic sufficient to lead to a rejection of the null hypothesis of no first-order serial correlation ($a = 0.05$).

The import demand for sablefish from the United States (Table 3) performed well using just three explanatory variables to capture variations over the twenty-seven year modeling period.

Table 3. Japanese Import Demand for Sablefish from the United States.

Dependent variable: Per-Capita Japanese Import Quantity of Sablefish from the United States.

Variable	Estimated coefficient	One-sided p-value	Mean-level elasticity
Real import price	-0.021	<0.001	-1.91
Real per-capita income	1048.8	0.029	2.78
Real price of meat	0.401	0.004	3.38
Constant	-0.361		

$R^2 = 0.79, DW = 1.83, DoF = 23$

The mean-value own-price elasticity shows the import demand for sablefish to be elastic, indicating that increased Alaska landings, and subsequent increases in increased Japanese imports, would increase Japanese sablefish import expenditures to the United States, all else equal. This is not surprising since sablefish is a relatively high-valued fish whose landings have been on a steady decline since 1988, when landings were over three times what they are today. As found by Huppert and Best (2004), imports of sablefish are also very sensitive to changes in the Japanese economy as measured by consumption expenditures. This relationship will be further explored later in the paper.

The decision to include the real producer price index of meat as a substitute good for sablefish is supported by the very strong statistical relationship shown in the estimated equation. It is not surprising that the Japanese consumer, in choosing whether to buy sablefish, will make a decision partly based on the price of alternative meat products. The cross-price elasticity indicates that for this time period a one-percent increase in the Japanese price of meat would be associated with a 3.38 percent increase in the Japanese import quantity of U.S. sablefish without a corresponding adjustment in import price (in reality, with nearly all Alaska sablefish being exported to Japan, the price of imported sablefish would adjust to clear the market). The high sensitivity of Japanese import demand to meat prices was expected because sablefish consumption is relatively minor in comparison to consumption of other meat products sold in Japan. Accordingly, small changes in the price of meat can lead to large changes in meat consumption relative to the total available amount of sablefish on the Japanese market.

Initial estimations of the demand equation included a variable for season length. IFQs have been both theorized and demonstrated to shift the primary demand for a fish species outwards (Wilen and Homans 1994, Herrmann 1996 and 2000). Primary market price increases followed from the slower pace of the fishery, which improved quality from better handling and also allowed for producers to take advantage of extending supplies to the higher price fresh fish market. However, nearly all US exports of sablefish, both pre- and post-IFQs are frozen prior to shipping.

Accordingly, IFQs were not found to boost consumer prices from extending the supply of sablefish to the Japanese fresh fish market. Any potential price shifts from quality improvements in the post-IFQ Alaska fishery were not statistically found in the import model by inclusion of either a season length variable or indicator variable that marked the pre- and post-IFQ periods. Perhaps any quality differences, if they exist, were too small to capture with price movement.

The U.S. export supply of sablefish to Japan (Table 4) is modeled as a function of the Alaska sablefish landings, and the real export price. This equation also exhibits strong statistical properties and, in particular, the p-value on landings is highly significant (the two-sided t-value was 16.1) with the real export price is significant at the 5% level.

Table 4. U.S. Export Allocation of Sablefish to Japan.

Dependent variable: U.S. Exports of Sablefish to Japan.

Variable	Estimated coefficient	One-sided p-value	Mean-level elasticity
Alaska landings	0.884	<0.001	1.19
Real export price	61960848	0.028	0.30
Constant	-6892149		

$R^2 = 0.95, DW = 2.10, DoF = 24$

The coefficient on U.S. sablefish landings indicates that a one kilogram increase in Alaska sablefish harvest will lead to a 0.88 kilogram increase in sablefish exports to Japan, all else equal. This reflects that the vast majority of Alaska landings have been exported to Japan since the complete exit by 1986 of the Japanese fleet from U.S., Canadian and Soviet Union sablefish fisheries (Sonu 2000). Finally, the estimated model provides statistical evidence that there is some modest responsiveness of export quantities to changes in the Japanese import price. The export price elasticity indicates that as the Japanese import price (in U.S. dollars) increases (decrease) by one-percent the exports allocated to Japan will increase (decrease) by 0.30%. This demonstrates that exports are not highly sensitive to changes in the export price, but nevertheless there are limited alternative markets (exports to other countries and a domestic market) that provide some pressure to the Japanese export price. This is a relationship that was not previously found in Huppert and Best (2004) when they modeled the sablefish export supply to Japan as a function of just total allowable catch using a time period of 1987 to 2003. While their principle finding still holds, that the Alaska sablefish quota is the dominant explanatory variable of exports to Japan, the estimated model may have identified an increasing influence of alternatives markets, which have grown in recent years, on export price.

Alaska sablefish exvessel price is modeled as a function of the Alaska export price to Japan and the daily average landings (Table 5). With just two explanatory variables the equation has good fit statistics with an R^2 of 0.85 and a DW of 1.73. The p-value on both the export price and on the average daily landings are significant at the 1% level.

Table 5. Alaska Derived Exvessel Demand for Sablefish.

Dependent variable: Real Alaska Exvessel Sablefish Price.

Variable	Estimated coefficient	One-sided p-value	Mean-level elasticity
Real export price	0.465	<0.001	0.810
Daily Average Landings	$-1.29E^{-8}$	<0.001	-0.035
Constant	0.010		

$R^2 = 0.85, DW = 1.73, DoF = 24$

The coefficient on the Japanese export price indicates that a one dollar per kilogram increase (decrease) in the export price will lead to a \$0.465 increase (decrease) in the exvessel price, all else equal. In percentage terms, a 1% increase (decrease) in export price leads to a 0.81% increase (decrease) in the exvessel price, all else equal. This strong relationship between the Japanese price of sablefish and the Alaska exvessel price is consistent with the findings of Squires et al. (1988) and Huppert and Best (2004). The coefficient on average daily landings is negative, as expected. The mean-level elasticity indicates that as the average daily catch decreases (increases) by one-percent exvessel price will increase (decrease) by 0.035%.

Unit root tests were performed on the deflated prices using the augmented Dickey-Fuller test (10% critical level). Tests indicated that real prices were nonstationary. The equation in which extra care was needed to protect against spurious correlation is the exvessel price equation. Tests on this equation indicate that exvessel prices and (export price and daily landings) are co-integrated.

Market Model Historical Simulations

Individual equation goodness-of-fit statistics are used to incorporate contemporaneous and inter-temporal linkages that exist within the market response model. These interdependencies are explicitly incorporated into the model simulation, where each of the equations in the market response model is solved for its reduced form. Model simulations were conducted using the Newton algorithm in SAS (SAS 2011). The historic simulation was performed on the system over the years 1988-2014. The goodness-of-fit (GOF) statistics are reported for the three exogenous untransformed variables: the Japanese import price of sablefish PIJUY (PIJUY = PIJUYR*JCPIF), the Japanese Import Quantity of Sablefish QIJU (QIJU = QIJUC*JPOP) and the Alaska Exvessel Price (PEX = PEXR*UPPIF) presented in Table 6. The GOF statistics indicate that the model generally performs well in estimating historic conditions.

Table 6. Historical simulations.

Variable	*r*	*MA%E*	*RMS%E*	Theil-U Decomposition *UM*	*UR*	*UD*	*U1*
Japanese Import Price (PIJUY)	0.90	8.3	10.5	0.00	0.02	0.98	0.099
Japanese import Quantity (QIJU)	0.98	7.0	9.1	0.00	0.00	1.00	0.083
Alaska Exvessel Price (PEX)	0.92	14.1	18.9	0.00	0.00	1.00	0.161

Where *r* is the estimated correlation between the observed and predicted values; *MA%E* is the mean percent error; *RMS%E* is the root mean percentage error; *UM* is the bias component of the Thiel U decomposition, an indication of systematic error, *UR* is the variance component of the Thiel U decomposition, an indication of unsystematic error; *UD* is the covariance component of the Theil-U decomposition; and *U1* measures the predictive ability of a forecast. By construction, UM + UR + UD =1 and it is desirable for *UD* to be close to 1. The Theil inequality statistic *U1* is equal to 0 for a perfect forecast, 1 if the model forecast is no better than a naïve forecast (a forecast based on the previous time period's value), and greater than 1 if the model forecasts are worse than the naïve forecast.

The correlation coefficients between actual and predicted values ranged between 0.90 and 0.98, the mean absolute percent errors ranged between 7.0 and 14.1, and the root-mean-squared percent errors ranged between and 9.1 and 18.9. The Theil inequality coefficient (*U1*), which ranges between 0.08 and 0.16, indicates that the predictive accuracy of the model far exceeds the predictive accuracy of a naïve forecast of no change.

Total Revenues and Optimal Static Harvest Levels

Sablefish are a long-lived and highly mobile species. The annual recruitment success rate of juvenile sablefish reaching maturity has high inter-annual variation. Alaska sablefish harvest has declined since it peaked in 1988 at just over 37 thousand mt. The 2014 harvest was just over 11 thousand mt. The steady downward trend in biomass and Total Allowable Catch has had serious economic implications to harvesters and processors and has placed substantial downward pressure on overall fishery revenues, even if decreased landings were required for maintaining healthy stocks. The ability to anticipate the effects of sablefish TACs, set to achieve biological objectives, to the economic performance of the fishing industry are limited by the absence of an up-to-date economic model that captures the relationship between harvest levels, prices, and revenues under both pre- and post-ITQ management. The market model presented here can be used for planning purposes by fishery managers and industry to better understand how changes in TACs and harvest levels will translate to changes in fishery revenues. It should be noted that fishery revenues may be directly or inversely related to fishery harvest depending on the sensitivity of prices to changes in landings.

Static total exvessel demand and revenue curves for 2014 are estimated by simulating the effects of various 2014 harvest levels on sablefish exvessel price, holding all else equal. To estimate these curves, 1000 draws are made from a multivariate normal distribution on the estimated covariance matrix of the error terms and used to perturb the covariance matrix of the parameter estimates. The new parameter estimates are then employed in simulations using the Newton Algorithm and the means of the estimated endogenous variables; the associated 5^{th} and 95^{th} percentiles are calculated as well to provide a 90% confidence interval.

In the baseline simulations, the simulated 2014 Alaska sablefish exvessel price was $8.12/kg with a 90 percent confidence interval of $7.40/kg to $8.80/kg. The actual 2014 Alaska exvessel price was reported as $7.91 (Welch 2014) or 2.5% lower. We subsequently used “add factors” to adjust the reduced form exvessel price intercept so that the estimated 2014 exvessel price projected to the actual price (Intrilligator 1978) and then simulated exvessel price by changing landings, holding all other variables at their 2014 levels. The estimated 2014 exvessel demand and revenue curves are provided in Figures 5 and 6.

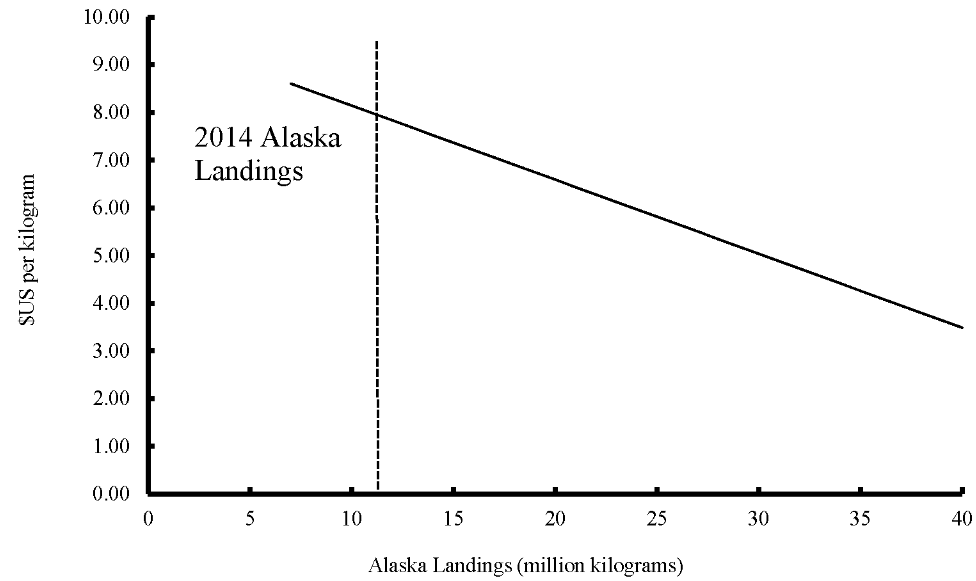

Figure 5. Simulated 2014 Alaska exvessel price changes for increased (decreased) Alaska catch levels of sablefish (million kilograms).

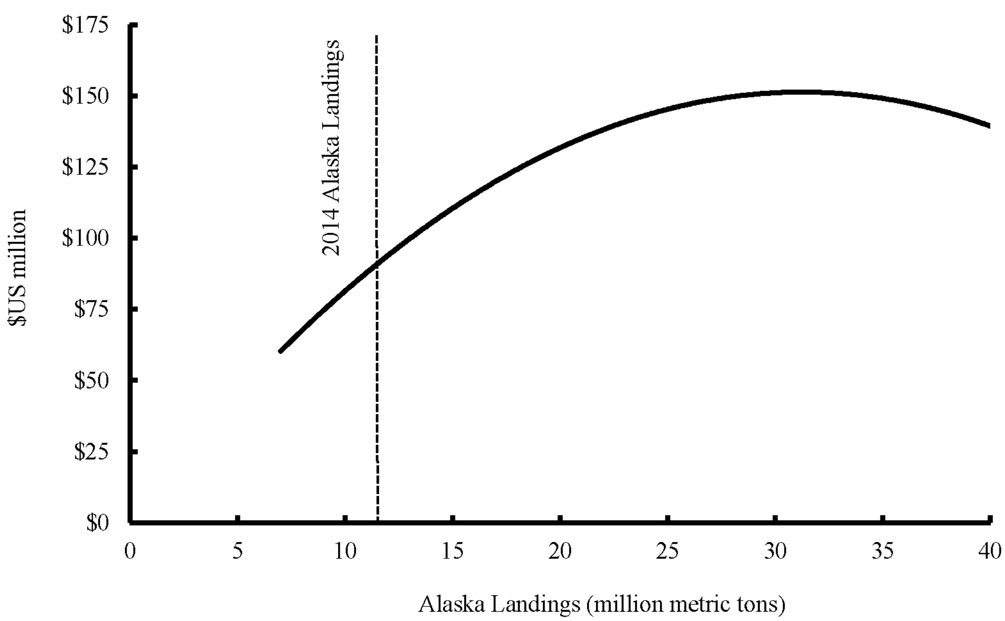

Figure 6. Simulated exvessel revenues ($ million) as a function of Alaskan landings of sablefish.

Because the 2014 landings are the lowest during the 27-year modeling period, the corresponding exvessel prices are less sensitive to changes in landings than what would have been found in years of higher harvest (all else being equal). Therefore, increases in sablefish landings will increase short-run revenues. This is the same result that was found for the Alaska halibut fishery, which entered into IFQ management in 1995 under the same program as sablefish (Herrmann and Criddle 2006). Simulated ex-vessel revenues peak at $151 million dollars when landings reach just over 31 thousand metric tons. Although Alaska landings of 31 thousand metric tons is far larger than current landings of 11.5 thousand metric tons, it is still smaller than the 1988 landings of 37.2 thousand metric tons, the first-year of the modeling period. To reiterate, given the gradual decrease in Alaska sablefish harvest, it is anticipated that any increase in quota will lead to higher exvessel revenues in the short-run.

Individual Transferable Quotas

The Alaska and British Columbia sablefish fisheries entered a period of fundamental change beginning in 1991 when the Canadian Department of Fisheries and Oceans (DFO) implemented an individual vessel quota (IVQ) program for their commercial sablefish and halibut fisheries. In the same year, NPFMC approved a long-term transition to an IFQ program for both Alaska sablefish and halibut fisheries, which took effect in 1995. The introduction of the quota system for the Alaska fisheries significantly increased the length of the fishing seasons. The 1994 Alaska's sablefish fishery was open for 14 days whereas in 2014 it was open for 245 days. The lengthened season increased fishery catch rates and decreased the harvest of immature fish (Sigler and Lunsford 2001). It is estimated (Sigler and Lunsford 2001) that variable costs to catch the quotas were reduced from 8% to 5% of landed value following IFQ implementation.

To simulate the effect of the Alaska IFQ program on sablefish exvessel prices and revenues, the model was recalibrated using the 1994 season length of 14 days in model simulations (as if the Alaska IFQ program had not been put into place) with predictions from the base model (see table 7). Introducing this shortened season length, representative of the pre-IFQ race-for-fish conditions, results in predicted Alaska sablefish exvessel prices being reduced to $5.79/kg from the actual 2014 price of $7.91/kg. The simulation model results indicate that the IFQ program resulted in a 36.7% increase to Alaska sablefish exvessel prices. This translates to a $24 million increase in 2014 revenues that is attributable to the IFQ program.

Table 7. Simulated sablefish 2014 annual exvessel prices ($/kg.) and exvessel revenues with and without implementation of the Alaska IFQ program.

	Alaska exvessel price ($/lb)	Exvessel revenue ($ U.S. million)
With IFQ Program	7.91	90,823,231
Without IFQ Program	5.79	66,424,841
Predicted increases due to Alaska IFQ program	2.12	24,398,389
Predicted increases due to Alaska IFQ program (%)	36.7%	36.7%

The exvessel price and revenue forecasts under IFQ management and the prior conventional (race-for-fish) management for the modeling period (1988 to 2014) are shown in figures 7 and 8. In figure 7, the price effects of IFQ management are evident, as real exvessel prices under the program consistently exceed those that would have occurred under conventional management. The change in fishery real exvessel revenues under the two management programs is even more pronounced (figure 8).

Figure 7. Simulated sablefish annual real (base year 2014) exvessel prices ($/kg.) with and without implementation of the Alaska IFQ program 1988-2014.

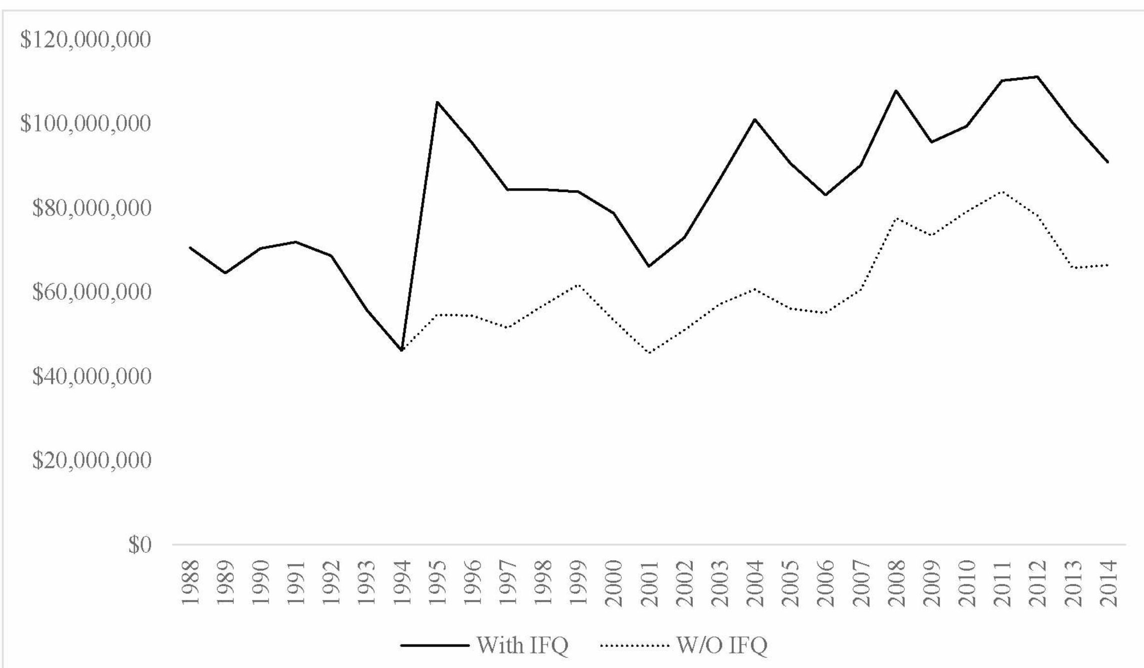

Figure 8. Simulated sablefish annual real (base year 2014) exvessel ($) revenues with and without implementation of the Alaska IFQ program (1988-2014).

It is estimated that without the IFQ program, due to the steady decrease in landings between 1988 and 2014, real exvessel revenues would have declined by 6% between 1988 and 2014. However, with the IFQ program real exvessel revenue has increased by nearly 30% over this period, indicating that the IFQ had beneficial revenue gains.

Sensitivity to Changes in the Japanese Economy

While the popularity of sablefish appears to be growing in the United States and other secondary export markets, Japan remains the dominant market and the principle driver of sablefish prices at the wholesale and exvessel levels. Japanese wholesale buyers continue to pay a premium for the larger, higher oil content sablefish of Alaska and British Colombia. Two primary macroeconomic factors that affect Japan's consumption and buyer's behavior are exchange rates and income levels. The market model was simulated to examine the effects of exchange rates to Alaska sablefish exvessel prices. Based on past studies and economic theory, it is expected that a strengthening yen will increase Japanese demand, which will lead to higher prices received by Alaska fishermen. The historical relationship between exchange rates and exvessel prices is shown in Figure 9.

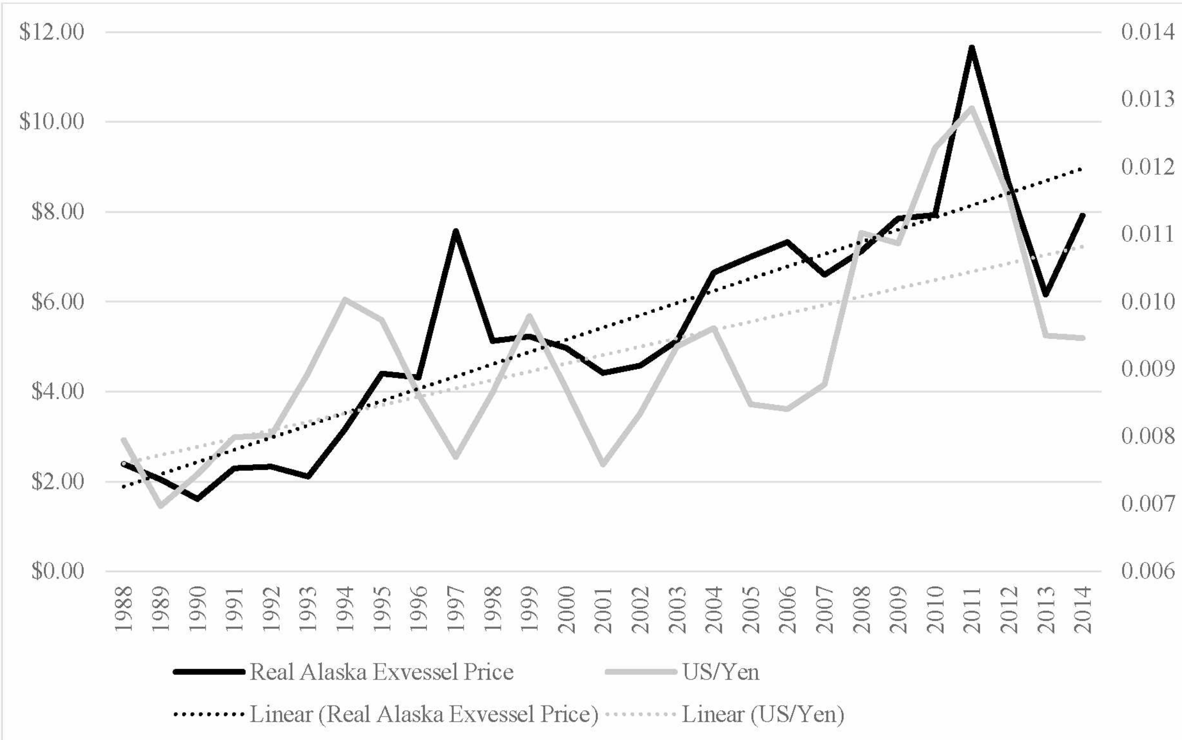

Figure 9. Real Alaska sablefish exvessel prices ($/kg.) (base 2014) and U.S. Japanese exchange rate ($/¥) 1988 to 2014.

During the modeled time period, exchange rates were highly variable, with the yen, in general, strengthening against the US dollar (although, it has substantially weakened in the past 2 years). For example, the extremely high 2011 sablefish exvessel price coincided with the strongest yen during the modeled period and has been cited as the principal contributing factor to the price spike (Welch 2011). Even with recent declines, the 2014 yen had appreciated 19% against the U.S. dollar since 1988. The simulated effect of the 2014 exchange rate, all else held constant, is shown in Table 8. In simulations, when the yen strengthens (weakens) by 5%, the Alaska exvessel price increases (decreases) by slightly more than 4%.

Table 8. The simulated effects of exchange rates ($/¥) on the 2014 exvessel price of sablefish ($/kg.).

Exchange Rate (% of 2014 value)	Alaska exvessel price ($/kg.)	Percentage Change From Base
75%	6.27	-20.8%
80%	6.60	-16.6%
85%	6.93	-12.5%
90%	7.26	-8.3%
95%	7.58	-4.2%
100%	7.91	0.0%
105%	8.24	4.2%
110%	8.57	8.3%
115%	8.90	12.5%
120%	9.23	16.6%
125%	9.56	20.8%

Changes to Japanese income over the modeling period have had the opposite effect on the sablefish market to that of exchange rates. The ongoing lethargic performance of the Japanese economy has put downward pressure on sablefish expenditures and prices. Japan suffered through the severe recessions of the 1990s (Hayashi and Prescott 2002, Huppert and Best 2004) and its recovery has been sluggish. The market model was simulated to examine the sensitivity of Alaska sablefish prices to changes in per capita Japanese income, as represented by consumer expenditures. The results of the sensitivity analysis are presented in Table 9.

Table 9. The simulated effects of changes in Japanese consumption expenditures on the 2014 exvessel price of sablefish ($/kg.).

Japan Consumption Expenditure (% of 2014 value)	Alaska exvessel price ($/kg.)	Percentage Change From Base
75%	6.54	-17.3%
80%	6.82	-13.8%
85%	7.10	-10.3%
90%	7.37	-6.8%
95%	7.65	-3.4%
100%	7.91	0.0%
105%	8.18	3.4%
110%	8.44	6.7%
115%	8.71	10.0%
120%	8.97	13.3%
125%	9.22	16.5%

To summarize, a 5% increase (decrease) in Japanese consumer expenditures leads to an approximate 3.5% increase (decrease) in Alaska exvessel prices. This indicates that if Japan's real consumption expenditures had held at its pre-recession early 1990s levels, the predicted 2014 Japanese exvessel price would have been $9.13/kg, or $1.22/kg (15.4%) higher than it was in 2014, all else equal. This finding of a strong relationship between the Japanese per-capita expenditures and exvessel prices should be expected given the dominance of the Japanese market and alternative markets that are still emerging.

Conclusion

The sablefish commercial fishery is one of the most lucrative fisheries in Alaska and it is closely linked to the Japanese market. Despite its importance, current market models of the sablefish fishery are lacking. This study combines what we have learned from previous analyses with current fishery and market conditions for Alaska sablefish to update and improve upon past economic analyses.

Through model estimation and simulations that incorporate simultaneous changes in supply and demand, we are able to isolate changes in landings, management regimes, exchange rates and the Japanese economy on the Alaska sablefish prices and revenues. Based on model results, decreased landings have decreased short-run revenues over what they could have been if the stocks had been healthier. Reduced harvests have raised prices but not enough to completely compensate for the loss of landings. It is estimated that landings could triple from current levels before prices would decrease enough that additional landings would cause revenues to decrease. Our model also indicates that the IFQ sablefish program led to substantial increases in Alaska exvessel prices and revenues over what they would have been under a continuation of the race for fish. These revenue gains to fishermen mirror what has been found in the halibut fishery (Herrmann and Criddle 2006). Model results also underscore that Alaska sablefish export and exvessel prices are highly sensitive to fluctuations in the Japanese economy.

Alaska sablefish landings in recent years are similar to the low levels experienced during the mid-1980s. During that period, high Japanese fishing effort led to stocks that were nearly over-exploited. "Since 1988, relative abundance has decreased substantially" (Hanselman et al. 2014, pg. 594). Low biomass and associated landings have contributed to a sablefish market that can accommodate higher harvests. While these conditions have long been thought to be conducive to the expansion of sablefish aquaculture, reliance on a single product dominant market may have kept exvessel prices too low for aquaculture to emerge as a major source of sablefish. The persistent decline in sablefish biomass, combined with a soft Japanese economy, has had long-term impacts to fishery revenues, prices. To the extent that management can increase the fisheries biomass and domestic and export markets other than Japan can be more fully developed, will be key to the sustained financial health of the sablefish fishery.

Chapter 3 The Need for Further Work: Bioeconomic Modeling

Alaska's sablefish fishery is among the most important fisheries to the state. Although sablefish only accounts for about 1% of commercial landings, they fetch some of the highest exvessel prices per pound and so represent over 7% of the value of commercial landings. They require sound management that is successful in achieving objectives protecting the fisheries and the fish (please see the Appendix for a further discussion on management). In addition, the frequent collapses of other fish species suggest that past management policies have not been sufficiently conservative in the presence of dynamically variable stocks. Overfishing is a global phenomenon that is a consequence of increases in fishing technology and competition. Historically the race to fish in many fisheries has strained fish populations and the ecosystem that surrounds it. In the United States, the eight Fishery Management Councils optimize a variety of objectives to ensure ecological longevity and economic efficiency along the U.S. coasts. Alaska's joint federal and state management manages some of the richest fisheries in the world and arguably, some of the most sustainably managed.

Making decisions about a fishery requires in-depth knowledge about the life history of the fish before it is caught, and what happens to the fish after it is harvested. A variety of tools are available for assistance in decision-making. Stock assessments provide an in-depth evaluation for Alaska's commercial fisheries; identifying forecasts and safe catch limits based on historical performance and structural statistical estimates utilizing survey data. Stock assessments are just one example of analyses that provide a framework for identifying optimal harvest levels. Economic analyses, such as this one, also provide another point of view for decision makers. A potent instrument that combines stock dynamics with economic analyses is a bioeconomic model. Due to the scope of this research and problems with data performance, a bioeconomic analysis was beyond the scope of this thesis project. However, the next step for sablefish is combining the stock dynamics in the water with the economics out of the water.

I originally set out to build a bioeconomic model of the sablefish fishery. Combining the market model with a stock dynamic model would provide a simulation that could be used to explore the dynamic interplay of ecological and economic systems. A bioeconomic model evaluates how harvest levels and carrying capacity of sablefish impact ex-vessel prices and international market demand. The final desired outcome is to compare our optimal yield to actual exploitation rates, providing a benchmark for efficient and effective management. For a sustainable yield curve, the objective is that harvest levels closely follow how much the stock can repopulate itself. If the rate of harvest surpasses the rate of increase (recruitment plus growth), there will be an overall decline in the fish stock. In an optimized bioeconomic system, population biomass will be relatively stable over time.

Recruitment, growth rate, predation, and spawning female biomass all inherently affect the current biomass levels. Harvest levels from fishing effort, both direct and incidental, impact the stock biomass and is one of the few variables that can be modified. NMFS stock assessment models do not model recruitment with a stock-recruitment relationship either; instead they use mean recruitment and annual recruitment deviations (Hanselman et al. 2014). Initially I built a model that was comprised of two equations: a stock dynamics equations and a stochastic recruitment draw. The model did an excellent job of modeling past variations in sablefish biomass. For our sustainable yield simulation, I needed to include a way to continuously increase population biomass, and since recruitment was not behaving as expected I used a stochastic draw to select from historical recruitment levels. While including a structured model for recruitment would have been valuable, including random draws from historical recruitment levels became the viable solution for what we were trying to achieve. However, as mentioned earlier, the large range of observations for recruitment was reflected within our models and was persistently a problem, and it was ultimately this issue that stalled our progress.

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Appendix: Sablefish Notes

Historical Sablefish Management

Sablefish was harvested locally since the 1900s, but it did not take off as a commercial fishery until the 1940s. It was primarily caught incidentally to halibut, without its own established fishery for the first half of the 20th century. Sablefish fishing efforts were also concentrated near fishing ports and remained small until the 1950s. Due to its high oil content, the first substantial efforts for fishing sablefish commercially started during World War II. They were used for fish oil tablets for the troops (Green et al. 2014).

Sablefish is harvested either using fixed gear, such as longlines or pot gear, or trawling gear. Alaska region stocks were originally fished by Japanese longliners in the 1950s, peaking in 1972 with a catch estimated at 36,776 metric tons (Hanselman et al. 2014). In comparison, catch for 2014 was 11,476 metric tons. The majority of these vessels were Japanese, but there was also substantial representation from Russia and Korea. This period prompted management measures to limit foreign catch rates, but it was too late. Sablefish population was in decline from overfishing (Sigler and Lunsford 2001).

With the lucrative bounty of the Alaskan seafood industry and collapsing stocks, there was growing concern that U.S. marine resources facing extinction in the near future. Coupled with the national response to the wave of industrialization and its externalities, this dismal forecast prompted legislative action. Other acts passed in this political climate include National Environmental Protection Act (1960), Clean Water Act (1972), and the Endangered Species Act (1973). In 1977, the landmark Magnuson Stevens Fishery Conservation and Management Act (MSFCMA) was passed, which gave the federal government jurisdiction over an Exclusive

Economic Zone (EEZ) which extended 200 miles from the coast. Eight regional advisory councils were established to set catch limits and fishing harvest guidelines.

Alaska had the lion's share of seafood production. The North Pacific Fishery Management Council (NPFMC) entirely advised fishing efforts off the Alaskan coast, with the National Marine Fisheries Service (NMFS) administering the fishing permits. After the MSFCMA was passed, foreign fishing was phased out, replaced by eager U.S. efforts, mostly from Washington and Oregon. In the late 1970s through the 1990s, many fishermen remember this as a time of "highliners" or millionaire fishermen. Regulations were reactionary to overharvesting; if vessel lengths were set, they became wider. If a fishing opener was three days, it was a race to fish without thought to safety concerns. Fishermen easily found the loopholes in regulations and benefitted. NMFS needed a new strategy before they saw more fisheries collapse. Alaska was a facing a classic tragedy of the commons dilemma. Fishermen knew whoever went faster and fished better, regardless of the risks of overfishing; they were going to reap the largest benefit. In the 1990s, the sablefish season was only open for a few weeks with a minimum of 14 days occurring in 1994.

In 1995, the Halibut and Sablefish IFQ programs were implemented in response to the stock decline and the dangerous derby-style both fisheries had become. Sablefish and halibut are both harvested similarly with fixed gear but sablefish are generally found at greater depths and are a smaller volume fishery. Halibut also have several stakeholder groups, including commercial, sport fishing, and subsistence, which delayed their quota program process. NMFS allotted quota share based on ten years of landing data per sablefish permit holder and closed the fishery to new participants. When it was confirmed that the IFQ program would be implemented for sablefish, they also included halibut within the program. The current IFQ quota participants can buy and sell their quota share and now have an invested interest in protecting sablefish into the future. The

Individual Fishery Quotas (IFQ) were implemented for the fixed gear fishery, which caught the majority of sablefish in Alaska. Consolidation of the fleet, higher catch per unit effort (CPUE), and decrease in crew mortality are some of the outcomes of this important management change.

Present Sablefish Fishery

The current season runs from the middle of March to November with the majority of the landings taking place in May and June (Hanselman et al. 2014). The IFQ is starting its twentieth year in effect and it is seen as a model for a properly managed fishery. Fixed gear accounted for approximately 91% of the catch in the last ten years. The remainder went to trawler vessels (Hanselman et al. 2014). The IFQ program, like many "fishery investment" management strategies is experiencing a "graying of the fleet," with quota share owners retiring and required capital to enter the fishery excludes younger fishermen.

Management Areas

Federal Management

Due to their high movement patterns, sablefish are assessed as a single stock in Alaska. The bulk of the commercial sablefish catch off of Alaska is managed by NMFS, with regional Fishery Management Plans (FMP) for the GOA and BSAI. Catch quotas, or Total Allowable Catch, have been allotted to IFQ shareholders based on their historical catch as a percentage of the TAC. There are four management areas to apportion exploitation in the Gulf of Alaska (GOA): Western GOA, Central GOA, West Yakutat/Southeast Outside, and two in the Bering Sea/Aleutian Islands (BSAI). Sablefish are caught primarily with longline gear, with pot gear increasing in popularity due to whale depredation (Peterson et al. 2014). There is also sablefish bycatch in trawl fisheries in federal EEZ waters. The majority of sablefish are caught in federal waters, managed under NMFS.

State Management

Adult sablefish mostly occur along the continental shelf margin and along the continental slope, which lies in near shore in some areas off Alaska; inshore waters fall under state jurisdiction. Fisheries have been established in state waters (0-3 nautical miles from shore) in Southeast Alaska, Prince William Sound, Cook Inlet, and in the Aleutian Islands.

Some of these fisheries are managed similarly to the federal fisheries. Three major state fisheries exist which are limited entry and are located in Prince William Sound, Chatham Strait, and Clarence Strait in Southeast Alaska. In response to the 1995 federal IFQ program, Alaska Department of Fish and Game established two minor open-access fisheries in Cook Inlet and the Aleutian Islands for fishermen who were not eligible to receive IFQ in the initial allocation. The Cook Inlet and the Aleutian Islands sablefish fisheries are managed under Guideline Harvest Levels (GHL), which are based on past harvest, fishery performance, and the NMFS stock assessment. Most of the fishing effort in state waters utilizes longline gear. A single trawl vessel in the Prince William Sound qualifies for the limited entry program. Pot gear is increasing in popularity as a deterrent to depredation by sperm whales and orca. The Aleutian Island fishery allows for most types of fishing gear.

The Global Sablefish Market

Sablefish's white, buttery fillets have a firm texture that is more luxurious than Pacific cod or pollock. It has high oil content similar to salmon but it doesn't taste fishy. In World War II, it was harvested for fish oil pills for the troops. In the 1950s, the Japanese fishing effort sent it back to

Japan. It has not been popular in the U.S. and Europe due to taste preferences that have only recently begun to change. The new wave of conscientious consumers is seeking out sustainably caught fish like sablefish, which has put it on the menu in Western countries.

The most significant substitute is Patagonian toothfish (*Dissostichus eleginoides*), also known as mero in Japan or Chilean sea bass in the U.S. The toothfish has the same firm, white flesh as sablefish and was originally imported into Japan when sablefish was short in supply and prices were increasing (Asakawa 2014). However, the toothfish fishery has been in decline due to mismanagement and illegal fishing efforts (Biology, 2011). A previous report by Hastie (1989) on sablefish identified chum salmon as a substitute, for winter soups in Japan. This is inaccurate for today's consumption patterns as noted in personal communications with Asakawa (2014), because of its high quality and high price. Instead it is sold as kirimi (in steaks) for grilling or in a marinade. Sashimi and sushi are not popular sablefish dishes because of parasites and wax ester, which causes digestive issues (Asakawa 2014).

Sablefish is nearly all exported to Asia and primarily to Japan. The majority of sablefish exports are from Alaska, followed by British Columbia, and the West Coast of the U.S. In their research about the processor effects of the IFQ program, Matulich and Clark (2003) noticed that the IFQ changed halibut from frozen low quality frozen product available seasonally to high quality fresh product. Sablefish continued in the same frozen product sent to Japan and other Asian markets without adjustments after the IFQ.

Canadian Sablefish Aquaculture

Canadian aquaculture has supplied a steady minimal stream of sablefish into the international market and should be noted as an additional supplier of sablefish. The U.S. has not pursued sablefish aquaculture ostensibly due to the distribution of the sablefish habitat being almost entirely in U.S. waters. However, the low levels of production and the small amount of aquaculture sites do not make sablefish aquaculture competitive with wild sablefish harvest. Sablefish have the potential to lower the market price, but aquaculture costs are high and "benefits are exported while costs are entirely absorbed within Canada (Sumalia et. al 2005)." Low profit margins constrain operational economics of scale that would otherwise impact the high ex-vessel prices sablefish fishermen rely on.

Finally, sablefish is not a volume fish; it is highly popular in Japan and its popularity is increasing in other parts of the world. The international market could absorb a substantial abundance of sablefish beyond the current carrying capacity of the North Pacific Ocean. It is a superior fish that never belongs in fish sticks.