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An Econometric Market Model for the Pacific Halibut Fishery[1]

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Abstract The Alaskan and British Columbian fishery for Pacific halibut has undergone substantial restructuring over the last decade from a regulated open-access no-holds-barred derby that largely relied on frozen inventories to satisfy market demand to a slow-paced individual quota-based fishery that has reorganized supply chains to deliver high-quality fresh product throughout a protracted season. We have developed a simultaneous equation model of the markets for Pacific halibut and used simulations based on our model to examine: (1) linkages between harvest and revenue; (2) exvessel price and revenue-induced consequences of the Alaska IFQ program; (3) likely exvessel price and revenue effects of the proposed elongation of the halibut season; and, (4) potential effects of the emergence of competing supplies from halibut aquaculture.

Key words Pacific halibut, market econometric model, ITQs, halibut farming

JEL Classification Codes C3, Q2.

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Introduction

Pacific halibut are managed under the Halibut Convention of 1923, a bilateral agreement between the United States and Canada. The treaty established the International Fisheries Commission, now the International Pacific Halibut Commission (IPHC), a scientific body with responsibility for conducting stock assessments and recommending conservation measures for halibut in the Pacific Northwest, Gulf of Alaska, Aleutian Islands, and Eastern Bering Sea. In 1976, the Commission's jurisdiction was extended to the 200-mile fisheries conservation zones established pursuant to the Fishery Conservation and Management Act (FCMA) in the United States and corresponding legislation in Canada. Canadian and U.S. halibut fishers were excluded from each other's territorial and extended jurisdiction waters in 1978. Although the IPHC retains authority to establish area specific harvest limits, each nation is responsible for allocating catches among its various user groups ensuring that the sum of commercial, sport, and other removals within its jurisdictional waters does not exceed the regional specific IPHC quotas. The IPHC sets and monitors commercial halibut catches in ten statistical regions. The current boundaries of the IPHC statistical regions are represented in Figure 1.

The organization and management of the commercial fishery for halibut has undergone two significant changes over the last decade. First, beginning with the 1991 season, the Canadian Department of Fisheries and Oceans (DFO) transformed management of the British Columbia halibut fishery from regulated open access to an individual vessel quota (IVQ) program. Next, beginning with the 1995 season, the North Pacific Fisheries Management Council (NPFMC) implemented an individual fishery quota (IFQ) program for halibut fisheries in Alaskan waters.

Other issues that have also presented ongoing and increasing challenges for halibut managers include halibut bycatch in other commercial fisheries and growth of halibut sport fisheries. Halibut bycatch is subject to bycatch caps, but while bycatch monitoring is good on large vessels characteristic of the Bering Sea, many of the smaller vessels that fish in the Gulf of Alaska are not monitored, or are only partially monitored. Efforts to manage growth in the sport fishery include the halibut charter Guideline Harvest Limit (GHL) program to be implemented in 2005 and proposed implementation of IFQs in the U.S. halibut charter-based sportfishing sector (NPFMC 1997, 2000). On the horizon looms the potential that increasing production of farmed halibut will disrupt North American halibut markets and wild capture fisheries in much the same way that the rapid growth of salmon farming devastated the North American salmon industry (Herrmann 1994). In response to possible increases in farmed halibut, and because of the advantages of marketing fresh halibut, there have been proposals to increase the length of the halibut season from eight months to ten and one-half months (IPHC 2003, Muse 2005).

The lack of an up-to-date rigorous market model of the Pacific halibut industry has limited the ability of fishery managers to quantify the economic consequences of anticipated changes in the quantity of halibut available to the commercial fishery and to consumers. This study is intended to remedy, in part, this lack and to model the linkages between Pacific halibut harvest levels and revenues, to derive a total revenue curve, to examine the revenue effects from implementation of the Alaska halibut IFQ program, to anticipate the potential economic consequences of the likely expansion of farmed halibut production, and to explore the potential economic consequences of season elongation.

The Pacific Halibut Fishery: Four Issues

Total Allowable Catch and Associated Industry Revenues

Although there have been substantial fluctuations in halibut quota over the last fifteen years, halibut stocks are widely regarded as healthy and well-managed; quotas remain strong and the 2004 coastwide quota of 76.5 million pounds was the largest ever set by the IPHC (see figure 2). However, the lack of an empirical market model for Pacific halibut has led to uncertainty about the potential market implications of continued increases in the halibut TAC. For example, in 1999 the IPHC biologists recommended a coastwide quota of 86 million pounds and suggested that the quota could have been set as high as 100 million pounds. However, due in part to fears that even an 86 million pound quota would glut the market, the commission set the coastwide quota at 74.1 million pounds (Spiess 1998).

In general, these strong harvests have been accompanied by strong exvessel revenues with the exception of a decline in the Alaska exvessel revenues in the years that British Columbia prosecuted their Pacific halibut fishery with the IVQ program while Alaska was still under a regulated open-access fishery (see figure 3). Although halibut harvest quotas have been primarily set to support biological objectives, examination of the relationship between harvest, prices and revenues provides important insights into the economic consequences of changes in harvest quotas. Increased harvests do not necessarily mean increased revenues; at some point, increases in harvests begin to saturate markets and cause revenues to decrease. The pertinent questions are: how close is the market to saturation and how sensitive are revenues to increases in halibut supply occasioned by a potential expansion of halibut aquaculture.

Individual Transferable Quota

The Pacific halibut fishery entered a period of fundamental change in 1991 when the Canadian Department of Fisheries and Oceans (DFO) moved to prosecute the British Columbia Pacific halibut fishery using individual vessel quotas (IVQs), the Canadian version of individual transferable quotas (ITQs). Shortly later, the North Pacific Fisheries Management Council (NPFMC) followed suit by introducing the individual fishery quotas (IFQs) for Alaska waters beginning with the 1995 season. From 1976 to 1990, the season length in British Columbia declined from 123 to 10 days. In area 3A (Alaska), where derby-style fishing continued through 1994, the season decreased from 96 days in 1976 to just 2 days in 1994. The introduction of IVQs significantly lengthened the fishing season in British Columbia, and the introduction of ITQs significantly lengthened the fishing season in Alaska. Since Alaska adopted IFQs the season in Alaska and British Columbia has stabilized at 245 days (figure 4). The lengthened fishing season has allowed for increased fresh fish sales, better product quality, and a wider choice of processing options for fishermen, including the option of directly marketing their catches to wholesalers, retailers, institutional purchasers, and restaurants (Wilen and Homans (1994) and Squires et al. (1995), and Hackett et al. (2005)).

Changes in the spread between exvessel prices in Alaska and British Columbia during the transition from open-access to ITQs provide important insights into the effects of fishery rationalization. Before 1990 the spread between British Columbian and Alaskan exvessel prices for Pacific halibut averaged \$0.32 per pound. From 1991 through 1994—following implementation of IVQs in British Columbia and prior to the implementation of IFQs in Alaska—the average spread increased to \$0.95 per pound. In the immediate aftermath of IFQ implementation in Alaska (1995-1997), the average spread decreased to \$0.10 per pound. Since 1997, average exvessel prices in British Columbia and Alaska have been virtually identical (Figure 5). To date, there has been very little empirical analysis of the price and revenue effects of IFQs, yet these effects are extremely important to fishermen and processors. Indeed, perceptions about the division of IFQ-induced rents between the harvesting and processing sectors in the halibut fishery were influential in the decision to adopt a two-pie system (harvester and processor quotas with community protections) in the Bering Sea crab fisheries. This is likely to also be the case as the Gulf of Alaska's groundfish fisheries rationalization is being debated.

Halibut Farming

Until recently, discussions about the impacts of aquaculture on the profitability of Alaska's wild fisheries have been dominated by concerns about salmon. Recent advances in aquaculture production systems for cod and halibut have awakened concerns for the potential impact of aquaculture on the profitability of capture fisheries for those species.

> "With farmed halibut on the horizon, it is only prudent to ask the question if farmed halibut will be round two for Alaska's fishing industry" (Forster 1999, quoting Kate Troll, a Fisheries

> Specialist with the Alaska Department of Commerce and Economic Development Division of Trade and Development.).

The good news for the Alaska capture-based fishing industry is that halibut farming has not grown as quickly as expected. Although the grow-out phase has been very successful, the hatching technology has been slow and some of the effort initially focused on halibut farming has switched to cod farming. The bad news for the Alaska Pacific commercial halibut industry is that there still remains a tremendous amount of interest in farming halibut. The economic effects of competition from farmed salmon has put the Alaskan wild salmon fishery into an economic tailspin from which it has not yet recovered. It is not unreasonable to speculate that development of halibut aquaculture could have similarly profound effects on the capture fishery for halibut. Add the fact that Norwegians are largely credited with driving the farmed salmon revolution and that they are now farming cod, halibut, and even experimenting with king crab (Jystad 2003), and it makes a lot of sense for the Alaska halibut industry to be very nervous. Bruce Leaman, executive director of the IPHC, has stated that the IPHC is similarly concerned about the potential impact of farmed halibut (IPHC 2003).

Season Length

Since 1995 the Pacific halibut fisheries in British Columbia and Alaska have been running the exact same 245-day seasons from March to November. In part, because of the threat of farmed halibut, there have been suggestions that the Pacific halibut season be lengthened (IPHC 2003). The National Marine Fishery Service is investigating the desirability of lengthening the Alaska Pacific halibut season to 10.5 months (Muse 2005). Lengthening the season would mean a longer period of time that halibut could be sold fresh and would somewhat close the opportunity for farmed halibut to exploit the 120-day window that wild halibut is not fished.

> The halibut industry continues to be concerned about the threat posed by aquaculture of halibut. The primary focus of this concern is the loss of market share for wild fish, particularly during the period when the commercial halibut fishery is closed. Industry wishes to address this concern by having wild, fresh halibut on the market for as much of the season as possible. One mechanism to achieve this end is to extend the commercial halibut season beyond its present period March 15th – November 15th (IPHC 2003).

In a report prepared for the BC Ministry of Agriculture, Food and Fisheries, Gislason (2001) concludes that there will be strong demand for farmed halibut and that “it would be sold at a premium price in the four month off season for the wild fishery”. By lengthening the season, the wild fishery could potentially increase current revenues and prevent the farmed halibut industry from serving as the sole supplier of fresh halibut during these months. Wyman (2000) notes “The impact of the farmed product on the wild fishery depends on the role (quality, season, product form) the wild product serves in the marketplace.” Determining whether it would be desirable to lengthen the commercial season for Pacific halibut season requires an understanding of the potential biological and economic ramifications of changes in season length.

Literature Review

Of historical importance is the early work of Crutchfield and Zellner (1962)[1]. This pioneering work included an in-depth examination of the Pacific halibut fishery as it existed from its inception to 1960 and remains a classic today. Since this time there have been a handful of econometrically estimated models of supply and demand in the halibut market. In some of these models, estimation of a demand curve was the central focus while, in others, estimation of a demand curve was a necessary component of a model intended primarily to explore other aspects of halibut management. With few exceptions, previous studies of the demand for Pacific halibut have been formulated as single-equation reduced-form exvessel inverse demand functions. The use of a single-equation approach has often been justified on the grounds that supply is predetermined by factors outside of the market, i.e. set by the IPHC's biology-driven quotas. In a study examining the socially optimal rate of capitalization of halibut vessels, Schellberg (1993) estimated a derived exvessel demand equation for halibut landed in the Seattle port from 1946 to 1977. Schellberg used a logarithmic formulation and estimated real exvessel price as a function of harvest and a linear time trend. In a model of the British Columbia halibut fishery, Cook and Copes (1987) modeled the British Columbia exvessel price as a function of British Columbian harvests, season length (in area 2B), and the price of salmon. The same general market model was used by Conklin and Kolberg (1994) in their application of a generalized method for analyzing stability potential in discrete renewable resource models subject to open-access market based harvest activity. Lin et al. (1988) estimated a more complex reduced-form exvessel demand equation for North American Pacific halibut using IPHC annual data from 1955 through 1984. They modeled real exvessel price (combined Canadian and U.S.) as a function of North American landings, the length of the halibut season (area 3A), U.S. cold storage holdings, and the U.S. real wholesale price of all finfish. Lin et al. (1988) found a mean-level exvessel price flexibility of -0.18 suggesting that, revenues would increase in concert with increases in halibut landings even for substantial increases in landings relative to the mean (1955-1984) level, all else equal. Their equation also indicated that a one-percent increase in the number of fishing days would increase exvessel price by 0.15 percent, the first study to quantify a price-induced benefit of an individual transferable quota program that would lengthen the fishing season.

As part of a larger work on regulated open-access resource exploitation, Homans (1993) estimated separate exvessel and wholesale price equations for Pacific halibut. The wholesale price equation was estimated with two-stage least squares, where wholesale price was modeled as a function of harvest, marketing period length, and lagged wholesale price. The exvessel price equation was estimated using ordinary least squares and modeled as a function of current and lagged wholesale price, current and lagged harvest, and the marketing period. This formulation is based on the assumption that the market adjusts at the wholesale price level and that exvessel price is formed, in part, as a markdown of wholesale price. Using data from 1959 through 1978, Homans estimated a long-run wholesale own-price elasticity of -1.16 and exvessel price flexibilities that, depending on marketing period, ranged between –1.12 and -1.59.

Herrmann (1996) utilized three behavioral equations to model exvessel price formation in the British Columbian market for Pacific halibut: U.S. import demand for Canadian Pacific halibut; the Canadian supply of Pacific halibut to the U.S.; and, the exvessel price for British Columbian halibut. The equation system was estimated using three-stage least-squares on data from 1974-1994. Among other findings, Herrmann estimated a U.S. import own-price elasticity of B.C. Pacific halibut of –1.68. He estimated that a one-percent increase in season length would lead to a 0.13 percent increase in exvessel prices in British Columbia. He concluded that between 1991 and 1995, implementation of IVQs in British Columbia increased exvessel prices increased from $CDN 0.55 to $CDN 0.77 per pound, depending on year. Revenue increases due to the price increases were estimated to be a total four-year revenue increase of $CDN 23.2 million. Herrmann (2000) expanded on this model, adding a reduced-form Alaska exvessel price equation and estimating that approximately one-half of the exvessel price increases achieved by British Columbia under the IVQ system remained after 1995 when Alaska adopted IFQs.

Our model was designed to improve on previous models of halibut markets through inclusion of additional behavioral equations and by directly modeling the Alaska Pacific halibut wholesale price of demand and then providing the linkage between the Alaska wholesale price and both the Alaska exvessel price and the British Columbia export price. Not only does modeling these additional relationships improve model performance, it also enhances the suitability of the model for simulating scenarios that cannot be addressed with existing models. For example, this model allows the examination of the relationship of Alaska exvessel price to wholesale price for both historical and projected changes in the fishery.

The Market Model

Alaska and British Columbia produced virtually the entire supply of Pacific halibut traded in world markets during the years covered in this study. Because the main market for halibut is, overwhelmingly, the U.S. (other minor markets do exist) the world's price of Pacific halibut is assumed to be set in the U.S. market. Although the upper bounds on harvests are exogenously set according to biological criteria, the allocation of these harvests (to immediate consumption or inventory) is an endogenous choice. Our model of the equilibrium system for the supply and demand for halibut from Alaska and British Columbia can be represented by six behavioral equations and six market clearing identities; twelve endogenous variables and twelve equations. The behavioral equations included in the model are: (1) the U.S. derived wholesale demand for Pacific halibut; (2) the demand for U.S. inventories of Pacific halibut; (3) the export of Pacific halibut from British Columbia to the U.S.; (4) the price linkage between British Columbia exports to the U.S. and the U.S. wholesale price of Pacific halibut; (5) the derived exvessel demand equation for Pacific halibut from Alaska; and, (6) the derived exvessel demand for Pacific halibut from British Columbia (see Figure 6).

Simultaneous Demand and Supply Equations

U.S. derived wholesale demand $$P_t^{US\,R\,W} = f_1\left(QC_t^{US}, QC_t^{BC}, SEAS_t^{AK}, PPI_t^{US\,Meat\,R}, PPI_t^{US\,Fuel\,R}, INC_t^{US\,R}\right). \quad (1)$$

U.S. inventory demand $$INV_t^{US} = f_2\left(TAS_t^{US}, P_t^{US\,W}, P_{t-1}^{US\,W}, SEAS_t^{AK}\right). \quad (2)$$

British Columbian exports to U.S. $$QS_t^{BC} = f_3\left(LAN_t^{BC}, P_t^{Export\,R}\right). \quad (3)$$

British Columbian export price linkage $$P_t^{Import\,R} = f_4\left(P_t^{US\,R\,W}, SEAS_t^{BC}, SEAS_t^{AK}\right). \quad (4)$$

Alaska derived exvessel demand $$P_t^{AK\,Exv\,R} = f_5\left(P_t^{US\,R\,W}, LAN_t^{AK}, PPI_t^{US\,Fuel\,R}\right). \quad (5)$$

British Columbia derived exvessel demand $$P_t^{BC\,Exv\,R} = f_6\left(P_t^{BC\,Exp\,R}, CPI_t^{Can\,Fuel\,R}, SEAS_t^{AK}\right). \quad (6)$$

Market Clearing Identities

$$QC_t^{US} = \frac{LAN_t^{AK} + LAN_t^{WA} + \left(INV_{t-1}^{US} - INV_t^{US}\right)}{POP_t^{US}} \quad (7)$$

$$QC_t^{BC} = \frac{QS_t^{BC}}{POP_t^{US}} \quad (8)$$

$$P_t^{US\,R\,W} = \frac{P_t^{US\,W}}{PPI_t^{US\,IFF}} \quad (9)$$

$$P_t^{AK\,Exv\,R} = \frac{P_t^{AK\,Exv}}{PPI_t^{US\,IFF}} \quad (10)$$

$$P_t^{Import\,R} = \frac{P_t^{Import}}{PPI_t^{US\,IFF}} \quad (11)$$

$$P_t^{BC\,Exp\,R} = \frac{P_t^{Import}}{CPI_t^{Can\,Food}} EXCH_t \quad (12)$$

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

The U.S. derived demand wholesale real price ($P_t^{US\,R\,W}$) is hypothesized to be a function of the estimated U.S. per-capita consumption of Alaska (and Washington) halibut (QC_t^{US}), the per-capita consumption of imported British Columbia halibut (QC_t^{BC}), the season length ($SEAS_t^{AK}$), the producer price of U.S. meat ($PPI_t^{US\,Meat\,R}$) and fuel ($PPI_t^{US\,Fuel\,R}$), and real per-capita income ($INC_t^{US\,R}$) (equation 1). The Pacific halibut landed in British Columbia and Alaska are drawn from a single undifferentiated stock of fish. Because the vast majority of British Columbian landings are exported to the U.S., the British Columbia halibut per-capita import quantity into the U.S. is included as an endogenous variable in the same way as is Alaska halibut. To capture the marketing advantages of elongated seasons associated with individual fishery quotas the season length ($SEAS_t^{AK}$) (proxied by the season length of area 3A) was used in the derived wholesale demand equation. One of the largest revenue advantages of an individual fishery quota is that the season is slowed-down allowing an increased amount of halibut to be sold throughout much of the year on the higher-priced fresh market. Another marketing advantage of a more relaxed fishery is that both the fishers and processors can more carefully handle the fish, leading to a higher-quality product. Additionally, there is more time to search out the most lucrative markets. The empirical use of the season length as a demand shifter has been motivated theoretically and included in previous empirical studies (e.g., Lin et al., 1988; Cook and Copes, 1987; Homans, 1993; Casey et al., 1995; Herrmann, 1996 and 2000; and Knapp, 1997). From 1984 to 1994 (pre-Alaska Halibut IFQ management) the percentage of Alaska halibut processed fresh was just 14.3 percent. During the first three years after the IFQ was in place the fresh halibut production was 33.9 percent and has risen to nearly 50 percent in the last four years. The real producer price index for meat was included as a substitute for halibut ($PPI_t^{US\,Meat\,R}$). Meat was theorized to be a good aggregate substitute product because, as Herrmann (2000) notes,

> there is no overwhelming statistical evidence in the literature that any particular fish species or class of fish species might substitute for halibut. As halibut is one of the least 'fish'-tasting fish, it is likely that possible market substitutes for it range well outside the normal fish products.

The deflated price index for fuel ($PPI_t^{US\,Fuel\,R}$) is included as a general proxy for the real cost transporting the processed halibut to the retailer. As transportation costs increase the wedge widens between retail and wholesale price thus decreasing the price of the halibut at the wholesale level.

The demand for U.S. inventory of Pacific halibut (INV_t^{US}) (equation 2) is hypothesized to be a function of the current available supply (TAS_t^{US}), current and expected prices ($P_t^{US\,W}$ and $P_{t-1}^{US\,W}$) and season length. The demand for U.S. inventory of Pacific halibut was specified to incorporate both holding inventories for a buffer against running out of supplies as well as for speculative purposes. (Please see the Appendix for the development of a theoretical motivation for our specification of this equation.) As discussed, the longer the season length ($SEAS_t^{AK}$) the more fresh halibut will be processed in relation to frozen halibut. This will mean that there will be less halibut to hold in inventory as fresh halibut cannot be held more than a few weeks. Additionally, as the largest portion of the season length increases are from after the IFQ program was implemented, the harvest and marketing of halibut could be chosen to coincide more favorably to better market conditions lessening the need to hold inventory.

The bulk of British Columbian landings of Pacific halibut are exported to the U.S. (QS_t^{BC}) (equation 3). Thus, a major factor in allocation to the U.S. market is the exogenously determined (by the IPHC) landings (LAN_t^{BC}). A small amount of supply is consumed domestically, but there is virtually no export of British Columbian halibut to nations other than the U.S., so, the allocation to the U.S. is largely determined by the real export price ($P_t^{Export\,R}$). Ideally, there could be other variables included in this equation such as cost variables and a domestic market price, but we were unable to construct a reliable domestic market price series for Canada and the influence of energy cost proxies included in preliminary models were small and not statistically significant.

The imported price of British Columbia Pacific halibut to the United States (equation 4) was modeled as a price linkage equation. With the products essentially identical, with only one significant market, clearly the influence of the "law of one price" is evident and the British Columbia price is linked to the dominant domestic U.S. wholesale price (which is simultaneously influenced by the import of Canadian Pacific halibut) with differences being due to periods that the season lengths were altered because of differences in the timing of implementation of the IVQ and ITQ programs. From 1976 to 1990 the correlation between the U.S. wholesale price for Alaskan halibut and the imported price of British Columbian halibut is nearly perfect ($r = 0.96$). Starting in 1991, when the Canadian IVQ program for Pacific halibut went into effect, the imported price of British Columbia halibut increased in relation to the wholesale price of domestic halibut. This separation decreased beginning in 1995 when the Alaska IFQ program was implemented. These two structural changes are captured by the inclusion of the British Columbia and Alaska Pacific halibut season lengths ($SEAS_t^{BC}$, $SEAS_t^{AK}$). Nevertheless, it is clear that the British Columbia price is linked to the dominant domestic U.S. wholesale price with differences being due to periods that the season lengths varied because of differences in timing of implementation of the two individual transferable quota programs.

The derived exvessel inverse demand curve (equation 5) was formulated with the real exvessel price of Pacific halibut landed in Alaska ($P_t^{AK\,Exv\,R}$) being determined by the real wholesale price ($P_t^{US\,R\,W}$), the landings of Pacific halibut in Alaska (LAN_t^{AK}), and the real producers price index for fuel ($PPI_t^{US\,Fuel\,R}$). The exvessel price of Alaskan halibut can be characterized as a mark-down of the wholesale price (see for example, Homans 1993). The correlation between the wholesale and exvessel price from 1976 to 2002 is 0.94. A basic question is whether the exvessel-wholesale price relationship was altered after the Alaska halibut fishery was converted to IFQ-based management. Several variables were used to test whether the relationship between exvessel and wholesale price was altered after 1995. Alaskan season length ($SEAS_t^{AK}$) was included in a preliminary specification of equation 5 to account for a possible structural break between wholesale and exvessel price, however, the magnitude of the estimated coefficient was small and evidence for a structural break was not statistically significant. Alaskan landings were also included as an explanatory variable. Although exvessel price may be principally determined by the wholesale price, the bargaining position of the fishermen and processors can be expected to vary depending on the volume of the harvest. The bargaining position of the processors will weaken in years with low harvests and strengthen in years with large harvests. The real price of fuel was included to proxy the increased processor costs. As processors' costs rise the exvessel prices that they are willing to pay decrease.

The derived exvessel inverse demand curve for British Columbia halibut (equation 6) was formulated in the same way as the derived demand for Alaskan halibut. The real exvessel price of British Columbian halibut ($P_t^{BC\,Exv\,R}$) is modeled as a function of the real export price ($P_t^{BC\,Exp\,R}$), the real consumer price index for fuel ($CPI_t^{Can\,Fuel\,R}$) and the length of the Alaska halibut fishery ($SEAS_t^{AK}$). British Columbian landings were also included in a preliminary model specification, but were dropped from the final model because their effect was small and not statistically significant. In the same way that the exvessel price of Pacific halibut landed in Alaska is thought to be marked down from the U.S. wholesale price, the exvessel price of halibut landed in British Columbia is thought to be marked down from the U.S. export price. The correlation coefficient between British Columbian exvessel prices and export prices has been relatively strong over the last twenty years ($r = 0.80$).

The length of the Alaskan season was included to test whether British Columbian fishermen lost some of their bargaining power once the Alaskan fishery converted to IFQs and the Alaskan season lengthened. The real price of fuel was included to reflect the cost of transportation from British Columbian fishing grounds to U.S. markets. The recorded U.S. import price is a Free Alongside Ship (FAS) price. That is, it is a price paid for the halibut excluding all costs to bring the product into the United States. Therefore, it would be expected that as the cost of transportation increases (decreases) the wedge between the U.S. import price and the British Columbian exvessel price will increase (decrease).

Market Model Estimation

The aggregate model was estimated using annual data over the sample period of 1976 to 2002.[2] The equations were estimated using the three-stage least squares (3SLS). The estimated coefficients and goodness of fit statistics for each equation are reported in the following sections. Asymptotic one-tailed p-values are reported along with the parameter estimates. The p-values are estimates of the probability of a type I error on a one-sided null hypothesis that the true value of the estimated parameter is zero. All reported mean-level elasticities are of the generic form $for\ y = f(x):\ (\partial y/\partial x)(\bar{x}/\bar{y})$. Sometimes these are interpreted, or referred to, as "elasticities" and sometimes they are referred to as "flexibilities" such as the own-price flexibility of demand for inverse (price dependent) demand equations. The Durbin-Watson statistic (DW) was used to detect first-order serial correlation, a frequent indicator of model mispecification. 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 ($\alpha = 0.05$) (Greene 1993).

Equation 1 represents the U.S. derived wholesale demand for halibut. The coefficient estimates, t-statistics, p-values, and mean-level elasticities are:

Equation 1. U.S. derived wholesale demand.
Dependent variable: U.S. real wholesale price of Pacific halibut.

Variable	Estimated coefficient	One-sided p-value	Mean-level elasticity
U.S. per-capita consumption	-0.035	<0.001	-0.29
U.S. per-capita Canada imports	-0.123	0.024	-0.17
Alaska season length	8.17×10^{-6}	0.072	0.03
Real U.S. price meat	0.035	<0.001	1.78
Real U.S. price fuel	-0.014	<0.001	-0.54
Real U.S. per-capita income	88,156	<0.001	0.65
Constant	-0.009		

$R^2 = 0.87$, $DW = 2.18$

As anticipated, the supply of halibut sold on the domestic market is relatively inelastic and is principally affected by an exogenously determined supply (by the IPHC) with minor adjustments for changes in end-of-year inventories and very minor amounts of exports. Because of this, we have modeled the U.S. Pacific halibut wholesale price formation to include those explanatory factors that affect the price level at which the wholesale market clears. Using Alaskan and Washington landings (adjusted for changes in inventory) as an approximation for domestic consumption, the mean level own-price flexibility (1976-2002) is -0.29, all else equal. Changes are smaller for the U.S. real wholesale price with respect to the mean-level of imports from the smaller British Columbian landings of Pacific halibut with the cross-price flexibility being -0.17. A one-percent increase in season length, on average, increased wholesale price by 0.03 percent.

Our decision to include the real producer price index of meat (meat, poultry, and fish) as a substitute good for halibut is supported by the strong statistical relationship. It is not surprising that the U.S. consumer, in choosing to buy or not buy halibut, will make a decision partly based on the price of other meat products (both fish and non-fish). The price flexibility indicates that over this time period a one-percent increase in the U.S. price of meat was associated with a 1.78 percent increase in the wholesale price of halibut. The fact that this is a rather large number is not surprising because the relative consumption of other meat sold in the U.S. far surpasses the consumption of halibut and small changes in the price of meat can lead to relatively large changes in meat consumption relative to the total available amount of halibut on the U.S. market. The income level in the U.S., as measured by U.S. disposable personal income, is also a significant explanatory variable. At the mean-level, a one-percent increase (decrease) in disposable personal income is expected to increase (decrease) the wholesale price by 0.65 percent.

The variable used as a proxy for the cost (real price) of transporting processed halibut to the retailer was the deflated price index for fuel. As the cost of transporting the processed halibut from the processor to the retailer increases the amount that retailers are willing to pay for halibut decreases, decreasing the wholesale price (FOB). This decrease in wholesale price is exacerbated if the wholesaler, with few options other than the domestic market, seeks to retain the original exported quantity of halibut. At the mean-level, a one-percent increase in fuel costs leads to a 0.54 percent decrease in the purchase price of halibut.

Equation 2 represents changes in U.S. inventories of halibut. The coefficient estimates, p-values, and mean-level elasticities are:

Equation 2. U.S. inventory demand equation.
Dependent variable: Natural log of U.S. Pacific halibut ending inventories.

Variable	Estimated coefficient	One-sided p-value	Mean-level elasticity
Natural logarithm of total available supply	0.646	<0.001	0.64
Natural logarithm of U.S. wholesale price	-1.074	0.008	-1.07
Natural logarithm of U.S. lagged wholesale price	0.966	0.009	0.97
Natural logarithm of Alaska season length	-0.107	0.004	-0.11
Constant	4.581		

$R^2 = 0.55$, $DW = 2.26$

All of the estimated slope coefficients in the inventory equation were statistically significant at the one-percent significance level. However, the model fit (R^2) is rather low, indicating that only 55 percent of the variation in the natural log of the ending inventory levels can be explained by observed variations in the explanatory variables. This is not unexpected since the ending inventory levels are annual values recorded at the end of the calendar year, a rather arbitrary reference period for much of the modeled time-period when the halibut season was limited to just a few days in the middle of the summer. If the model had been based on monthly data it may have been easier to estimate an inventory equation with a better fit.[3] Additionally, other variables, such as interest rates and fuel costs, were initially included in the model as proxies for the cost of holding inventory, but were not found to be influential or statistically significant.

The mean-level elasticity on the U.S. inventory equation indicates that a one-percent increase (decrease) in total available supply (beginning inventory plus current landings) will lead to a 0.64 percent increase (decrease) in ending inventory levels, all else constant. An increase (decrease) in the current wholesale price will decrease (increase) inventories by an estimated 1.07 percent at the mean. Increases (decreases) in the lagged prices reflect changes in price expectations and were found to increase (decrease) inventory levels by 0.97 percent at the mean. A one-percent increase in season length decreases inventory levels by 0.11 percent all else equal.

Equation 3 represents the British Columbia export supply of halibut. The coefficient estimates, p-values, and mean-level elasticities are:

Equation 3. British Columbia export supply equation.
Dependent variable: British Columbia halibut exports to the U.S.

Variable	Estimated coefficient	One-sided p-value	Mean-level Elasticity
British Columbia landings	0.562	0.001	0.67
British Columbia real export price	2.23×10^8	<0.001	0.93
Constant	-4,447,849		

$R^2 = 0.79$, $DW = 1.68$

The British Columbia export supply is modeled as a function of British Columbian landings of Pacific halibut and the real export price of Pacific halibut. The mean-level elasticities indicate that on average (all else equal) a one-percent increase (decrease) in landings would increase (decrease) exports to the U.S. by 0.67 percent and a one-percent increase (decrease) in real price would increase (decrease) exports by 0.93 percent.

Equation 4 represents the import price linkage for British Columbia halibut. The coefficient estimates, p-values, and mean-level elasticities are:

Equation 4. Import price linkage for British Columbia halibut.
Dependent variable: British Columbia real export price to the U.S.

Variable	Estimated coefficient	One-sided p-value	Mean-level elasticity
U.S. real wholesale price	1.176	<0.001	1.12
British Columbia season length	0.000024	<0.001	0.14
Alaska season length	-0.00001	<0.001	-0.04
Constant	-0.004		

$R^2 = 0.94$, $DW = 1.68$

The British Columbia real price for halibut exported to the U.S. is modeled as a function of the U.S. real wholesale price for domestic halibut, and the lengths of the British Columbian and Alaskan halibut seasons. The mean-level elasticities indicate that on average, a one-percent increase in the U.S. real wholesale domestic price of Pacific halibut will lead to a 1.12 percent increase in the price of imported British Columbia halibut. A one-percent increase in the length of the British Columbia halibut season was estimated to increase the U.S. import price by 0.14 percent, all else equal. Likewise, an increase in the length of the Alaska halibut season was estimated to decrease the import price by 0.04 percent.

Equation 5 represents the derived exvessel demand for halibut in Alaska. The coefficient estimates, p-values, and mean-level elasticities are:

Equation 5. Alaska derived exvessel demand.
Dependent variable: Alaska real exvessel price for Pacific halibut.

Variable	Estimated coefficient	One-sided p-value	Mean-level elasticity
U.S. real wholesale price	0.899	<0.001	1.23
Alaska landings	-3.05×10^{-13}	0.029	-0.09
Real U.S. price fuel	-0.003	0.058	-0.16
Constant	0.00019		

$R^2 = 0.90$, $DW = 2.01$

The mean-level elasticities indicate that, on average, a one-percent increase (decrease) in the real wholesale price will increase (decrease) the Alaskan exvessel price by 1.23 percent, all else equal.[4] The direct movements are somewhat tempered by changes in Pacific halibut landings. A one-percent increase (decrease) in landings will decrease (increase) the exvessel price by 0.09 percent, all else equal. The real price of fuel was included to proxy the increased processor costs; as processor's costs rise, the price that they are willing-to-pay for halibut deliveries decreases and a one-percent increase (decrease) in the real price of fuel will decrease (increase) the exvessel price by 0.16 percent.

Equation 6 represents the derived exvessel demand for halibut in British Columbia. The coefficient estimates, p-values, and mean-level elasticities are:

Equation 6. British Columbia derived exvessel demand.
Dependent variable: British Columbia real exvessel price for Pacific halibut.

Variable	Estimated coefficient	One-sided p-value	Mean-level elasticity
Natural logarithm of British Columbia real export price	0.030	<0.001	1.17
Natural logarithm of Canadian real fuel prices	-0.016	<0.001	-0.63
Alaska season length	-0.00002	0.020	-0.06
Constant	0.133		

$R^2 = 0.88$, $DW = 1.73$

The exvessel price for Pacific halibut landed in British Columbia was modeled as a function of the British Columbian real export price of Pacific halibut to the U.S., the real price index of energy, and the Alaskan season length. The equation was estimated in the linear-log form because the equation estimated in the linear form exhibited some serial correlation indicating that the functional form may have been incorrectly specified. The mean-level elasticities indicate that, on average, a one-percent increase (decrease) in the real export price of British Columbian halibut will result in a 1.17 percent increase (decrease) in British Columbian exvessel prices.

The real price of fuel was included to represent the cost of transportation from British Columbian fishing grounds to U.S. markets. The estimated coefficients indicate that a one-percent increase (decrease) in the real price of energy will lead to a 0.63 percent decrease (increase) in British Columbian exvessel prices. As the Alaskan season lengthens a one-percent increase in season length decreases the British Columbian exvessel price by 0.06 percent, holding all other variables including the export price constant. This indicates that British Columbian fishermen lost some of their advantage in export prices when Alaska implemented IFQs.[5]

Market Model Historical Simulations

Individual equation goodness-of-fit statistics are used to incorporate contemporaneous and intertemporal linkages, which exist within the market response model. These interdependencies are explicitly incorporated into the dynamic 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 2004). The historic dynamic simulation was performed on the system over the period from 1976 to 2002. The goodness-of-fit statistics reported Table 3 indicate that the model generally performed well in estimating historic conditions. The correlation coefficients between actual and predicted variable levels ranged between 0.75 and 0.96. The mean absolute errors ranged between 8.2 percent and 27.5 percent, and the root-mean-squared errors ranged between, and 10.5 percent and 44.4 percent. The Theil inequality coefficient (*U1*) indicates that the predictive accuracy of the model far exceeds the predictive accuracy of a "no change" forecast.

Results and Discussion

Total Revenues and Optimal Static Harvest Levels

The relationship between the production of raw goods and the revenues generated to the primary producer is a much discussed economic relationship. In the case of Pacific halibut, this fishery-wide relationship is between policy-regulated IPHC catch quotas and the resulting exvessel revenues generated to the halibut fleet. The exvessel revenues that fishermen receive depend on many factors such as relative bargaining strength with buyers (normally processors), the cost of processing and getting the fish to the end-markets, and the strength of the market for the final product.

A static total revenue curve for 2002 can be estimated by simulating changes in Pacific halibut prices given changes in the 2002 Pacific halibut landings. Draws from a multivariate normal distribution are made on the estimated covariance matrix of the error terms (the residuals computed from the parameter estimates) and used to perturb the covariance matrix of the parameter estimates. The new parameter estimates are then used in dynamic simulations using the same Newton Algorithm used in the historical simulations. The means of the estimated endogenous variables from 1000 draws as well as the associated 5th and 95th percentiles are calculated to give a 90% confidence interval.

The Pacific halibut total revenue curve was simulated for changes in the Pacific halibut harvests from Alaskan waters for 2002. In the baseline simulations the simulated 2002 Alaska exvessel price was $2.18 with a 90 percent confidence interval of ($2.00 to $2.38). The actual 2002 Alaska exvessel price was $2.21. The simulated 2002 Alaska exvessel revenue was ($126,774,089) with a 90 percent confidence interval of ($117,029,116 to $137,634,706). The actual 2002 Alaska exvessel revenue was $128,450,371. Because the simulated exvessel prices and revenues closely approximated actual exvessel revenues we will work with the simulated revenues without rescaling them to actual revenues.

As landings vary, revenues are affected in two ways: revenues vary as a direct consequence of changes in harvest levels and as a consequence of changes in exvessel prices as simulated from all the interactions reflected in the entire system of equations. The total revenue curve was estimated by varying both the 2001 and 2002 Alaskan halibut landings away from their 2001 and 2002 levels of 58.9 and 58.1 million pounds, respectively, while holding all other variables at their actual 2001 and 2002 levels (see Figure 7). [6] In the 2002 base year, 58.1 million pounds of halibut were landed in Alaska and sold at an exvessel price of $2.21. As landings increase from this level so does total revenue. As landings continue to increase, the change in exvessel price becomes increasingly sensitive to equal percentage increases in landings. Simulated exvessel revenues peak when landings reach 104.2 million pounds. At this point the simulated exvessel price is $1.51 and simulated exvessel revenues are $157.8 million dollars.[7] The relationship between the changes in landings and the simulated changes in exvessel prices are shown in Figure 8.

Effects of IFQs

To simulate the effect of the Alaska IFQ program on wholesale and exvessel prices, as well as exvessel revenues, the model was first simulated to estimate the Pacific halibut weighted annual average prices and revenues for 1995 through 2002. The model then was re-simulated to reflect what market conditions would have been if the Alaska IFQ program had not been put into place. That is, in these simulations, the Alaska season length was set to 2 days (the length of the 1993 and 1994 season) for 1995 to 2002. The prices and revenues under the simulated current fishery, and that of the simulated continuance of the race-for-fish fishery are compared in Table 4.

The Alaska IFQ program is estimated to have increased average wholesale prices (for 1995 to 2002) by $0.238 per pound and is estimated to have increased average exvessel prices by $0.213 per pound. An exvessel increase of $0.213 per pound over this time period translates to an average annual exvessel revenue gain of just under $11 million (an annual gain of approximately 10.5 percent).[8] Our model suggests that implementation of the Alaska IFQ program decreased exvessel prices in British Columbia by an average of $0.339 per pound over 1995 to 2002. This is close to Herrmann's (2000) estimate, based on a differently specified and simpler model that was estimated over a shorter time period. Herrmann estimated that the British Columbia exvessel price decreased by $0.27 per pound as a consequence of the implementation of Alaska's IFQ program.[9] Our results indicate that approximately 90 percent of the wholesale price gains from the Alaska IFQ program accrued to the fishermen who were allocated quota shares. This result is not unexpected if the processors are largely competing for the raw product. In a competitive market, as wholesale prices rise, processors can be expected to bid up the price of the product to cover their costs of production. If the cost structure is not significantly changed from the pre-IFQ period, then we would not expect the margin to change substantially.

Season Elongation and Potential Revenue Effects

Farmed salmon first infiltrated new markets by selling product primarily during the off-season (October to May). In this way, the product reached new consumers and did not face direct competition from fresh supplies of wild salmon; after a period of time, production costs fell and farmed salmon became readily acceptable as a substitute for wild salmon throughout the year. Similarly, farmed halibut is likely to be first sold during the months of November through March when the wild halibut fishery is currently closed. Consequently, industry groups have suggested that the IPHC consider the possibility of lengthening the Pacific halibut season to preempt, or at least slow, the establishment of farmed halibut in seasonal niche markets.

Regardless of the state of farmed halibut production, lengthening the Pacific halibut season should increase revenues by spreading the supply of "fresh" halibut over as much as two and one-half additional months each year. To explore the likely effects of season elongation, we used our model to run simulations with the Alaskan season lengths increased to 10 and one-half months (321 days) both with British Columbia keeping their current 245-day season length and with British Columbia matching changes in the Alaskan season length. The results of our simulation are reported in Table 5.

The projected increases in exvessel prices and revenues are a result of the increased availability of fresh halibut during the winter months. It is predicted that, if British Columbia keeps its current season length, the increase in the Alaska season length will raise Alaska prices and revenue by 2.7 to 3.2 percent; an increase in annual exvessel revenues of just over $4 million exvessel. If the season length in British Columbia is also extended to match the increased Alaska season length, simulated prices and revenue are reduced to increases of 1.6 to 1.8 percent; an increase in annual Alaska exvessel revenues of approximately $2.5 million exvessel. These gains are relatively modest compared to the gains attributed to IFQs but it is important to remember that with IFQs, the season length increased from little more than 2 days to 245 days, a much larger change than going from 245 to 321 days.

Whether lengthening the season would be advantageous to the industry depends on several factors, including changes in revenues, changes in fishing, processing, and management costs, and long-term biological impacts to this and other fisheries. Finally, even if the revenue increases are modest, if farmed halibut becomes increasingly more prevalent, the largest advantage of moving to a 321 days season may be to delay the penetration of farmed halibut into seasonal niche markets.

Farmed Halibut and Potential Revenue Effects

The State of Alaska is concerned about the possibility that farmed halibut could devastate the Alaskan halibut fishery much as farmed salmon devastated the Alaskan salmon fishery. In fiscal year 2003, the Alaska Governor's budget echoed these concerns in a list of "key department issues": "The Alaska fishing industry faces many serious challenges in the years ahead due to the increasing worldwide production of low-priced, high-quality farmed salmon and the imminent mass production of farmed halibut" (DCED 2001). Forster (1999) speculates that the intense competition from farmed halibut may be some time down the road:

> It does not present an immediate competitive threat to wild halibut, nor is it certain that farmed halibut will, necessarily, have a negative impact on the market for wild fish, especially in the short and medium term. What is certain, in this author's opinion; is that marine finfish aquaculture will continue its worldwide expansion and that halibut will succeed as a farm fish because it has attributes that make it well suited for this purpose (Forster 1999).

Much of the discussion about the potential impacts of farmed halibut is educated speculation, but given the economic disaster that salmon aquaculture precipitated on the race-for-fish salmon fishery, educated speculation about the potential impacts of halibut aquaculture can at least bring the issues to the forefront for discussion.

We used our model to more rigorously explore the potential effects of farmed halibut on prices and revenues in the Alaskan wild halibut fishery. The simulations were run conditioned on the greatly simplified assumptions that: 1) the market for halibut 15-20 years down the line will be similar to what it was in 2002; 2) farmed halibut will enter the existing U.S. markets through the same import channels as wild halibut from British Columbia, 3) the market will perceive farmed Atlantic halibut and wild Pacific halibut as perfect substitutes; and, 4) the wild halibut season will be elongated to 10½ months to compete with farmed halibut.

The first assumption is necessary because this is the model that was specified and estimated using information about market conditions through 2002. While it is likely that many factors will change in 15 to 20 years, it is difficult to know how they will change, whether they will resemble conditions observed in the past or whether they will represent entirely new conditions. Therefore, these simulations really ask what would have been the market effect in 2002 if farmed halibut production had instantly, and dramatically, increased. The second assumption also represents an assumption that the future will resemble the past and present. The U.S. has been and is the primary market for halibut and we assume that the U.S. will remain the primary market for halibut through the near future and therefore, that most farmed halibut, wherever produced, will be channeled into the U.S. market. However, it is likely that other markets will be developed and utilized. Because the most mature import channel is that from British Columbia, we assumed that farmed halibut will follow a similar channel. The third assumption, that farmed halibut is a perfect substitute for halibut landed in the wild-capture fishery, is necessary to simulate the effects in this model. However, this assumption is not that unreasonable as Forster and others report that, to date, farmed Atlantic and wild Pacific halibut (on the market place) have been "interchangeable". The simulations are for 25 percent increments of farmed halibut as a percent of Alaskan landings of wild halibut (up to 100 percent) (Table 6).

These simulations suggest that if farmed halibut were to be sold in the same markets that wild halibut is currently sold in, the resulting loss in exvessel revenue to the Alaskan fishery would be substantial. Of course, this scenario should be considered a worst case scenario, a warning that intense pressure on price and revenues are likely to occur if halibut farming continues to be developed as projected. If wild Pacific halibut prices decreased by as much as indicated it would also mean that farmed halibut prices would decrease similarly. Forster estimates that current costs to produce farmed halibut are between $2.43 and $2.79 per pound and that future (15-20 years) costs can be expected to be in the range of $1.45 to $1.89 per pound. Even with minimal transportation costs, the sale of farmed halibut into the same markets as wild British Columbian halibut would cease to be profitable as farmed production levels approached 50 percent of Alaskan landings. For an expansion of more than 50 percent of farmed production into the U.S. to occur, demand would need to expand or farmed halibut production costs would need to fall below projected cost levels. However, Forster (1999) suggests that:

> a more likely scenario would be that before exports of farmed halibut to the U.S. drove farmed prices down towards costs of production, that halibut farming countries would need to develop export markets in other countries as was done with salmon.

But there are also some differences between salmon and halibut. At the time that farmed salmon was being developed, salmon was consumed in more world markets than halibut is currently consumed in. The salmon season was significantly shorter than the current halibut season, limiting fresh salmon to the summer months whereas fresh halibut is now already available for two-thirds of the year. It seems unlikely that there is as much room for market expansion in the case of farmed halibut as there was for farmed salmon. In any case, it will be the cost of producing farmed halibut that will be the limiting factor and without significant new markets or market expansion; it would not take unthinkable amounts of farmed halibut being sold on the domestic markets to substantially affect revenues in the wild-capture fishery.

Discussion

While many of the world's fish stocks are in decline, biomass and harvest levels remain high in the Alaskan and British Columbian halibut fishery. The prices and revenues generated by the halibut industry are among all-time highs. The economic importance of this fishery to Alaska provides motivation for research to better understand the links between new management policies and changing area-wide quotas and the economic characteristics of a healthy halibut industry. This report summarizes the supply and demand for the Pacific halibut fishery.

Although the regional catch quotas set by the IPHC are ostensibly based on purely biological considerations, the quotas have occasionally been reduced to mitigate concerns about over-saturating halibut markets. Our market model suggests that under current demand conditions, revenues are constrained by the sustainable yield of halibut, not by consumer demand. That is, although increases in the quantity of halibut released into the exvessel and wholesale markets will result in decreased prices, the increased quantity can be expected to more than offset the decreased price, thus revenues will increase as landings increase up to the maximum sustainable level of landings under current environmental conditions. That is, our research does not find support for concerns that increases in the coastwide quota for halibut could glut the market unless those quotas exceed about 100 million lbs.

The Alaskan and British Columbian halibut fishery is often discussed as a type case of the changes that arise following the transition from an open access derby style fishery to a slow-paced individual quota based fishery. However, there have been conflicting interpretations of these changes. Conflicting interpretations have arisen in part because of the lack of baseline analyses before the implementation of IVQs in British Columbia or IFQs in Alaska, in part because of the lack of a rigorous market model to account for simultaneous changes in market conditions and catch quotas, and because of the lack of public access to verifiable information about harvesting, processing, and storage costs before or after IVQ/IFQ implementation. Because our model accounts for simultaneous changes in demand, supply, inventories, and important exogenous market factors that affect price and revenue formation, we are better able to differentiate between changes that are a result the implementation of IVQs/IFQs and changes that are a consequence of other sources of variations. Based on our model, we conclude that the introduction of IFQs in the Alaskan halibut fishery resulted in substantial increases in exvessel and wholesale prices while leaving exvessel-wholesale margins largely unchanged. Our results indicate that the vast majority of the wholesale price increase was used to bid up the exvessel price of Pacific halibut. Matulich and Clark (2003) suggest that as exvessel prices were bid-up, processors who had invested in nonmalleable capital that was unsuitable for profitable operation under the longer, slower IFQ fishery, lost market share to newer and more flexible processors. The timing of IVQ/IFQ implementation was particularly onerous for traditional processors because it came on the heals of the aquaculture-induced collapse of salmon prices, leaving processors increasingly reliant on revenues from processing halibut, sablefish, and other species that had been relatively inconsequential in the pre-farming heyday of salmon processing.

Alaska and British Columbia are again on the verge of watching a transformation in fisheries markets, this time driven by the growing levels of marine whitefish aquaculture. Our simulations suggest that if farmed halibut were to be sold into the same markets that wild halibut is currently sold in, the resulting exvessel revenue losses to Alaskan fishermen would be substantial. Although there are important differences between salmon and halibut markets, it would not take unthinkable amounts of farmed halibut being sold on the domestic markets to substantially affect the wild halibut industry. Will British Columbia permit halibut farming as it has permitted salmon farming? Will Alaska stand on the sidelines in halibut aquaculture as it has in salmon aquaculture? The answer to these questions will affect the degree to which Alaska and British Columbia will be benefited or harmed by halibut farming.

Regardless of whether Alaska and British Columbia permit halibut aquaculture within state or territorial waters or whether the U.S. National Marine Fisheries Service permits halibut aquaculture within the U.S. EEZ, a substantial growth of halibut aquaculture will exert downward pressure on wholesale and exvessel prices for wild halibut. Extending the wild-harvest season will slow, but not prevent, the successful penetration of farmed halibut. Nevertheless, under the restructuring that has occurred following the implementation of IVQs and IFQs, the halibut industry is in a much better position to weather competition from farmed halibut. However, it can be anticipated that the value of IVQ/IFQ shares will decline if wholesale and exvessel prices weaken as halibut aquaculture expands. Those quota shareholders and processors who have invested under the assumption of continued elevated wholesale and exvessel prices will face financial difficulties when the value of their assets declines to reflect softer prices much as salmon limited entry permit holders saw the value of their permits decline as the expansion of salmon aquaculture drove salmon prices ever lower.

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Appendix

Theoretical Formulation of the Inventory Demand Equation

The partial adjustment to ending inventories can be specified as a geometric mean of desired ending inventories and beginning inventories:

$$I_t = \left(I_t^d\right)^{\delta}\left(I_{t-1}\right)^{1-\delta} \tag{A1}$$

where I_t is current inventory; I_t^d is desired inventory; and δ is a parameter of adjustment where $\delta \in$ (0,1). Desired inventories are a function of current and expected prices and other exogenous variables:

$$I_d^t = \beta_o P_t^{\beta_1} P_t^{e\beta_2} z_1^{\beta_3} \tag{A2}$$

where P_t is current price; P_t^e is expected price; Z_1 represents predetermined variables; and the $\beta_i s$ are parameters to be estimated. For this equation, it is anticipated that $|\beta_1| > |\beta_2|$, implying that if both prices rise by an equal percentage, then more inventory would be sold in the current year and less would be held for the next year due to storage costs and risk aversion. One proxy for price expectation is a value proportional to the geometric mean of current and last year's prices:

$$P_t^e = \Phi\left(P_t^{\tau}\right)\left(P_{t-1}\right)^{1-\tau} \tag{A3}$$

where τ is a proportion parameter and $\tau \in (0,1)$. An equation for desired inventory is found by combining equations (A2) and (A3):

$$I_d^t = \beta_o P_t^{\beta_1}\left[\Phi\left(P_t^{\tau}\right)\left(P_{t-1}\right)^{1-\tau}\right]^{\beta_2} z^{\beta_3} \tag{A4}$$

or

$$I_d^t = \beta_0^* P_t^{(\beta_1+\tau\beta_2)} P_{t-1}^{(1-\tau)\beta_2} z^{\beta_3} \tag{A5}$$

To complete the partial adjustment specification equation (A5) needs to be substituted into equation (A1) for I_t^d. The current price has two effects on ending inventories. If for example current price were to rise, one effect would be a motivation to sell during the current time period while prices were high, this being captured by the parameter β_1. Another effect would be to motivate selling later in part because current prices are part of the future price expectation process. But assuming $|\beta_1| > |\beta_2|$ the effect of the current price can be negatively signed.

Another proxy for the price expectation process involves the adaptive price expectation:

$$P_t^e = P_t\left({P_t}/{P_{t-1}}\right)^{\tau} = P_t^{(1+\tau)} P_{t-1}^{-\tau} \tag{A6}$$

which, when substituted into (A2), yields:

$$I_d^t = \beta_o P_t^{(\beta_1+\beta_2(1+\tau))} P_{t-1}^{-\beta_2\tau} z_t^{\beta_3} \tag{A7}$$

For the coefficient on current price to be positive, β_1 must be greater than $\beta_2(1+\tau)$ in absolute value. This would be true if the expected price equals the current price under the previous assumption regarding the relative magnitudes of $|\beta_1|$ and $|\beta_2|$. If τ is greater than zero, then the price variable theoretically cannot be signed with absolute certainty. Nonetheless, it is anticipated that the net effect of a change in current price is inversely related to the level of ending inventories.

The speculative motive is only a partial explanation of why inventories might be held. Inventories also may be held due to a transactions motive as a buffer against running short of halibut supplies. For this reason LAN_t^{US} is included so that ending inventories are some fraction of beginning supplies of halibut, and the parameters on these variable are positively signed. The parameter on the lagged inventory has the expected sign between 0 and 1 since this is the range dictated by the partial adjustment hypothesis.

For our specified Pacific halibut inventory demand equation landings and beginning inventories are combined into total available supply to alleviate estimation problems with these variables specified separately. The inventory demand equation is transformed into a linear function by taking the natural logs of both sides of the equation.

Footnotes

[1] Republished in Crutchfield and Zellner (2003).

[2] The only exception to the time series being carried out to 2002 was for the quantity of Pacific halibut imported to the U.S. from British Columbia The 2002 estimate of these exports was not considered reliable and therefore was not used. Estimation and forecasting are carried out in the presence of missing values by forecasting the missing values with the current set of parameter estimates (SAS 2004).

[3] There have also been concerns over the quality of the voluntarily reported cold storage holdings. The concerns have led the National Marine Fisheries Service to discontinue the collection of this data after 2002.

[4.] We originally tested whether there may have been fundamental changes between the wholesale exvessel margins after Alaska implemented the IFQ program. Specifically, we might have expected the margin to have decreased due to the possibilities of decreased processing costs that may accrue as processors switch much of their processing from preserving and storing halibut to producing fresh halibut (Hackett et al. 2005). However, examining the real margins show that the absolute margin between wholesale and exvessel price (in 2002 dollars) was an identical 69 cents in the 8-year period before and after the implementation of Alaska IFQs. The annual percent of exvessel to wholesale price did rise modestly from 71.5% before Alaska IFQs to 74.0% after the implementation of Alaska IFQs. However, this slight increase was not large enough to be picked up in our models.

[5.] There appears to be some slight increase in the percentage of the British Columbia exvessel price to the British Columbia export price of Pacific halibut following the implementation of the British Columbia IVQ program: the percentage of exvessel to export price increased by 5% during this period from the annual average of a decade earlier. However, after the implementation of the Alaska IFQ program the percentage of the British Columbia exvessel price to that of the export price declined by 16%. The latter decline was picked up in the specification of the Alaska season length variable being included in the British Columbia exvessel price model, an indication that there was an additional negative affect on British Columbian Pacific halibut export prices beyond the reduction in export prices due to the Alaska IFQ program. The magnitude of the slight increase in the margin percentage for the period following the British Columbia IVQ program, but before the Alaska IFQ program was put in place, was not large enough to be captured by either the British Columbia season length variable nor an indicator marking the post British Columbia IVQ period.

[6] Again, both the 2001 and 2002 landings were changed to allow changes to inventory to be captured in 2002. Since any changes to landings will effect future years because of inventory changes, it was seemed more accurate to investigate changes to the 2002 season from simulated changes in landings for not only 2002 (in which inventory effects will show up in 2003) but also for 2001.

[7] In Figure 7, we see that Alaskan exvessel revenues would increase as Alaskan halibut landings increase to 104.2 million pounds. However, biological (or regulatory) factors, which may lead to changes in Alaskan landings, are likely to affect all ten IPHC regulatory areas (although not equally). Simulated Alaskan exvessel revenues peak, when simulated coastwide (combined Alaska, British Columbia and Washington) landings are varied proportionately, at 86.7 million pounds.

[8] Our estimates of the increase in wholesale and Alaskan exvessel prices is quite a bit lower than was estimated by Matulich and Clark (2003). Using the 1992-1993 and 1999-2000 seasons as benchmark periods, Matulich and Clark estimated that the Alaska IFQ program led to a $1.19 increase in wholesale prices and a $1.15 increase in exvessel prices. However, the difference between these two periods is the largest spread in any 7 year period over the last thirty-years (the time period for which accurate exvessel price data has been gathered). For example, if you look at the difference between the 1994-1995 and 2001-2002 average exvessel the price difference is just $0.11 per pound. Just using a year earlier, between 1991-1992 and 1998-1999 the spread is just $0.14 per pound.

[9] Herrmann (2000) predicted that, from 1991 to 1994, the British Columbia IVQ program increased British Columbia exvessel prices by $0.53 per pound. This was in line with a prediction of a price increase of $0.40 to $0.80 per pound by Canada Department of Fisheries and Oceans economist Bruce Turris before implementation of the Alaska IFQ program (Doherty 1990).

Table 1. Market model variable definitions

$CPI_t^{Can\ Food}$	Canadian consumer price index food [h]
$CPI_t^{Can\ Fuel}$	Canadian consumer price index for fuel (energy)[h]
$CPI_t^{Can\ Fuel\ R}$	Canadian consumer price index (real) for fuel (energy) ($P_t^{Can\ Fuel\ R} = P_t^{Can\ Fuel} / PPI_t^{Can\ Fuel}$)
$EXCH_t$	Canadian-U.S. exchange rate ($CDN/$U.S.)[b]
INC_t^{US}	U.S. personal disposable income (billion $U.S.)[b]
$INC_t^{US\ R}$	U.S. real per-capita personal disposable income ($INC_t^{US\ R} = INC_t^{US} / \left(PPI_t^{US\ IFF} \times POP_t^{US} \right)$)
INV_t^{US}	U.S. beginning inventories of frozen halibut (blocks, fillets and steaks) (lbs) [d]
INV_{t-1}^{US}	U.S. ending inventories of frozen halibut (blocks, fillets and steaks) (lbs) [d]
LAN_t^{AK}	Landings of halibut in Alaska (lbs) [f]
LAN_t^{WA}	Landings of halibut in Washington (lbs) [f]
LAN_t^{US}	U.S. landings of Pacific halibut ($LAN_t^{AK} + LAN_t^{WA}$) (lbs) [f]
LAN_t^{BC}	Landings of halibut in British Columbia (lbs) [g]
$P_t^{AK\ Exv}$	Exvessel price of halibut landed in Alaska ($/lb) [a]
$P_t^{AK\ Exv\ R}$	Exvessel price (real) of halibut landed in Alaska ($/lb) [i]
$P_t^{BC\ Exv}$	Exvessel price of halibut landed in British Columbia ($CDN/lb) [g]
$P_t^{BC\ Exv\ R}$	Exvessel price (real) of halibut landed in British Columbia ($P_t^{BC\ Exv\ R} = P_t^{BC\ Exv} / PPI_t^{C\ F}$)
$P_t^{BC\ Exp\ R}$	Price (real) of halibut exported to the U.S. from British Columbia . ($CDN/lb) [i]
P_t^{Import}	Import price of Canadian halibut in the U.S. ($/lb) [e]
$P_t^{Import\ R}$	Import price (real) of Canadian halibut in the U.S. ($/lb) [i]
$P_t^{US\ W}$	U.S. wholesale price of halibut ($/lb) [c]
$P_{t-1}^{US\ W}$	U.S. lagged wholesale price of halibut ($/lb) [c]
$P_t^{US\ R\ W}$	U.S. wholesale price (real) of halibut ($/lb) [i]
POP_t^{US}	U.S. population (millions) [b]
$PPI_t^{US\ Meat}$	U.S. producer price index for meats, poultry, and fish [b]
$PPI_t^{US\ Meat\ R}$	U.S. producer price index (real) for meats, poultry, and fish ($PPI_t^{US\ Meat\ R} = PPI_t^{US\ Meat} / PPI_t^{US\ IFF}$)
$PPI_t^{US\ IFF}$	U.S. producer price index for intermediate food and feed [b]
$PPI_t^{US\ Fuel}$	U.S. producer price index for fuel products and power [b]
$PPI_t^{US\ Fuel\ R}$	U.S. producer price index (real) for fuel products and power ($PPI_t^{US\ Fuel\ R} = PPI_t^{US\ Fuel} / PPI_t^{US\ IFF}$)
QC_t^{US}	U.S. per-capita consumption of halibut from Alaska (lbs) [i].
QC_t^{BC}	U.S. per capita consumption of halibut imported from Canada (lbs) [i]
QS_t^{BC}	Canadian exports of Pacific halibut to the U.S. (lbs)[e]
$SEAS_t^{AK}$	Pacific halibut season length in area 3A (days) [f]
$SEAS_t^{BC}$	Pacific halibut season length in area 2B (days) [f]
TAS_t^{US}	U.S. Total Available Supply of Pacific Halibut $TAS_t^{US} = LAN_t^{AK} + INV_{t-1}^{US}$ (lbs.)[d,f]

Table 2. Market model variable sources

(a)	Alaska Commercial Entry Commission, computer printouts. Juneau, Alaska, 2003.
(b)	Economagic. http://www.economagic.com, 2003.
(c)	Alaska Department of Fish and Game. Division of Commercial Fisheries. Commercial Operators Annual Reports (COAR). Computer Printouts, 2003.
(d)	U.S. Department of Commerce. Various Issues. Frozen Fishery Statistics, various issues: U.S. cold storage holdings of fishery products. National Marine Fisheries Service, Silver Springs Maryland various issues and NOAA website http://www.st.nmfs.gov/st1/market_news/index.html.
(e)	National Marine Fisheries Service. Foreign Trade Division. Collected by the U.S. Department of Commerce. Various computer printouts and Web Site, http://www.st.nmfs.gov/st1/trade/index.html.
(f)	International Pacific Halibut Commission, various annual reports annual and web site, http://www.iphc.washington.edu/halcom/about.htm.
(g)	Canada Department of Fisheries and Oceans. Commercial Catch Statistics. Vancouver, British Columbia, various issues and website, http://www.dfo-mpo.gc.ca/communic/statistics/Historic/main_e.htm.
(h)	Government of Canada, Statistics Canada, CANSIM$, http://cansim2.statcan.ca/.
(i)	See market clearing identities.

Table 3. Historical simulations.

				Theil-U Decomposition			
Variable	*R*	*MA%E*	*RMS%E*	*UM*	*UR*	*UD*	*U1*
U.S. wholesale price ($P_t^{US\,W}$)	0.93	8.2	10.5	0.00	0.00	1.00	0.095
U.S. inventory (INV_t^{US})	0.75	27.5	37.3	0.00	0.02	0.98	0.278
British Columbian exports to the U.S.(QS_t^{BC})	0.93	25.0	44.4	0.00	0.02	0.98	0.180
British Columbian export price to the U.S. (P_t^{Import})	0.96	8.4	10.8	0.00	0.01	0.99	0.092
Alaskan exvessel price ($P_t^{AK\,Exv}$)	0.82	15.7	23.1	0.00	0.00	1.00	0.173
British Columbian exvessel price ($P_t^{BC\,Exv}$)	0.91	12.6	17.1	0.01	0.03	0.96	0.135

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. These forecast measures are further described in Appendix A.

Table 4. Simulated annual exvessel and wholesale prices and exvessel revenues without implementation of the Alaska IFQ program (1995-2002).

	Wholesale price ($/lb)	Alaska exvessel price ($/lb)	Exvessel revenue ($ U.S. million)	BC exvessel price ($ U.S./lb)
Actual	2.742	2.015	101,694,344	2.126
Predicted without IFQ programs	2.504	1.802	90,963,180	2.464
Predicted increases due to Alaska IFQ program	0.238	0.213	10,731,164	(0.339)
Predicted increases due to Alaska IFQ program (%)	8.6%	10.5%	10.5%	(15.9%)

Table 5. Simulated 2002 Alaska halibut exvessel price and revenue changes from elongating the Alaska commercial fishing season length to 321 days (with British Columbia at the current 245 day season and expanding to match the 321 day season).

	Wholesale price ($/lb.)	Exvessel price ($/lb)	Exvessel revenue ($)
British Columbia 245 day season			
Actual season	2.90	2.21	128,450,371
Simulated increases under a 321-day season	0.08	0.07	4,171,171
Predicted with 321 day season	2.98	2.28	132,627,543
% Increase due to the season elongation	2.7%	3.2%	3.2%
British Columbia 321 day season			
Actual season	2.90	2.21	128,450,371
Simulated increases under a 365-day season	0.05	0.04	2,490,722
Predicted with 321 day season	2.95	2.25	130,941,093
% Increase due to the season extension	1.6%	1.9%	1.8%

Table 6. Simulated 2002 Alaska halibut price and revenue with hypothetical farmed halibut production (as a percent of wild Alaska halibut production) assuming an elongated 321 day capture Alaska and British Columbia fishery season.

Farmed halibut production as a percent of Alaska harvest	Simulated farmed halibut production (million pounds)	Wholesale price ($/lb.)	Exvessel Price ($/lb.)	Exvessel revenue ($ U.S. million)
0%	0	2.95	2.25	130,806,398
25%	14.5	2.61	1.94	112,896,854
50%	29.1	2.27	1.63	94,547,290
75%	43.6	1.93	1.31	76,132,607
100%	58.1	1.58	0.99	57,476,421

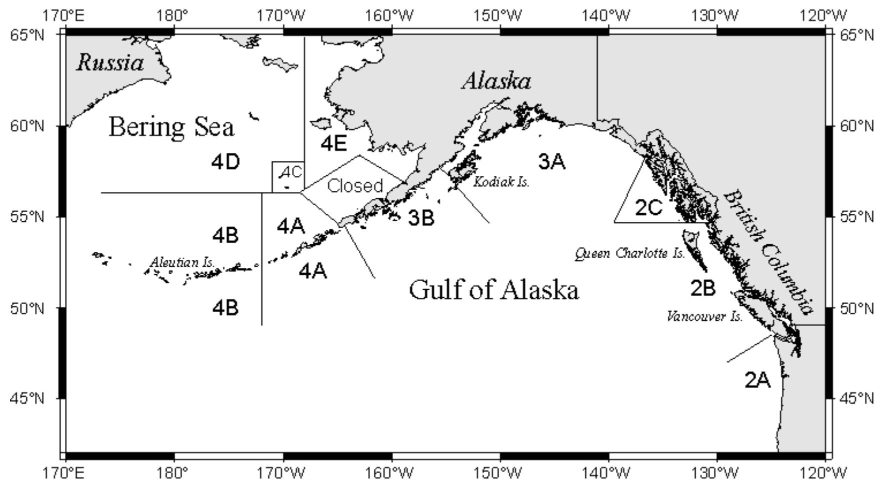

Figure 1. IPHC regulatory areas. Source IPHC 2005.
http://www.iphc.washington.edu/halcom/default.htm, Jan. 25.

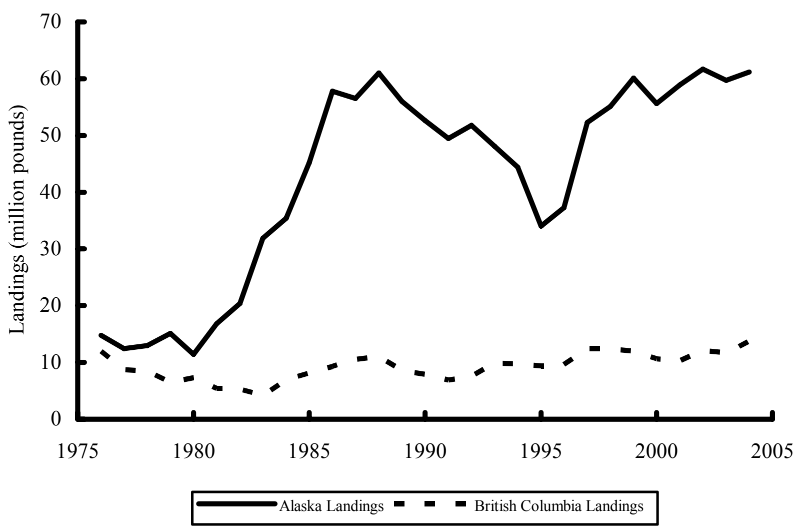

Figure 2. Alaska and Canadian landings of Pacific halibut (1976 to 2004).

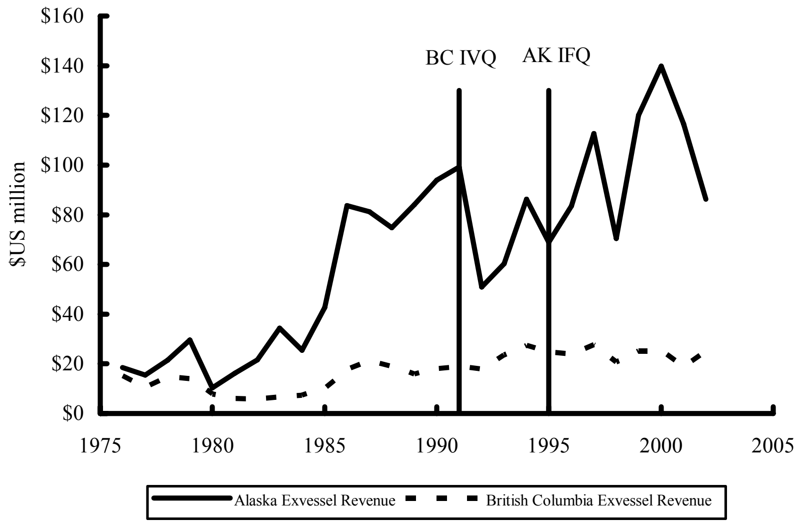

Figure 3. Exvessel revenues ($ million) from Pacific halibut landings in Alaska and British Columbia (1976 to 2002).

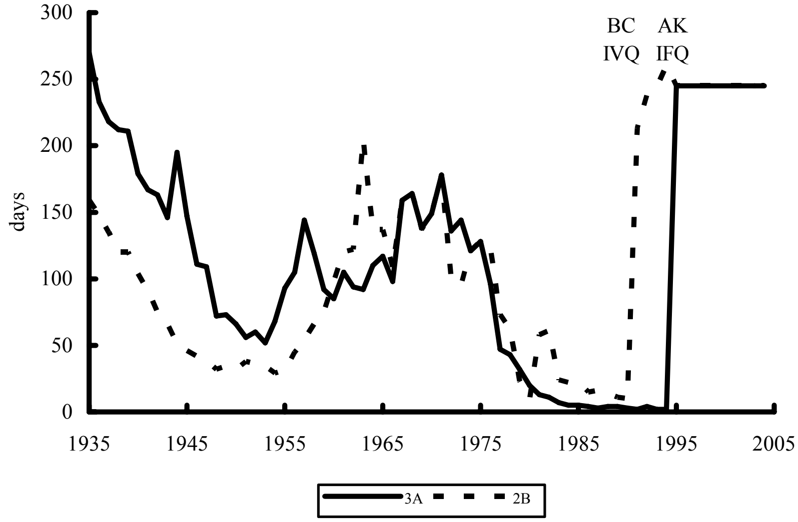

Figure 4. Commercial fishing season length in Pacific halibut management areas 2B and 3A (1935-2004).

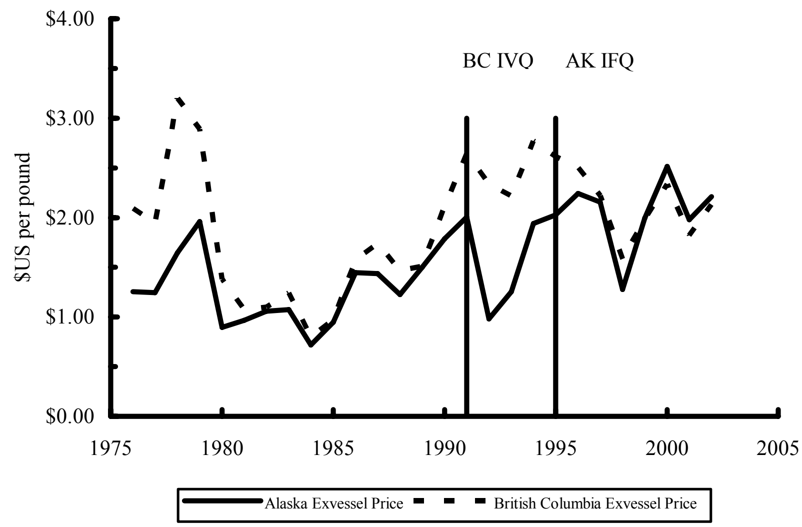

Figure 5. Exvessel price ($/lb) of Pacific halibut in Alaska and British Columbia from 1976 to 2002.

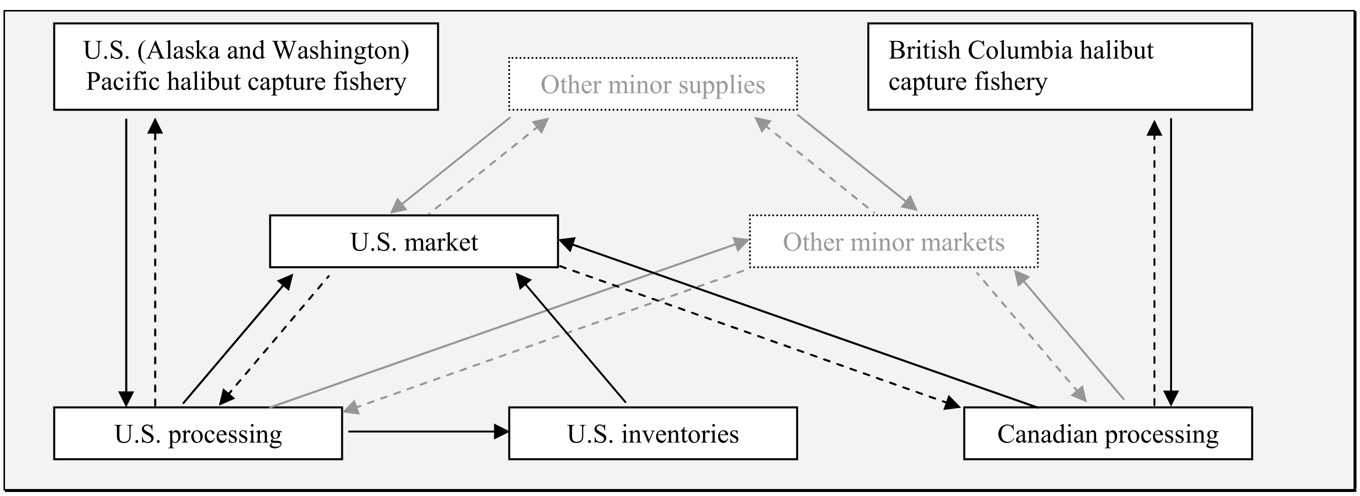

Figure 6. Product and financial flows in the Alaska and British Columbia halibut fisheries. Solid arrows represent product flows and dashed arrows represent financial flows. Light gray flows not modeled.

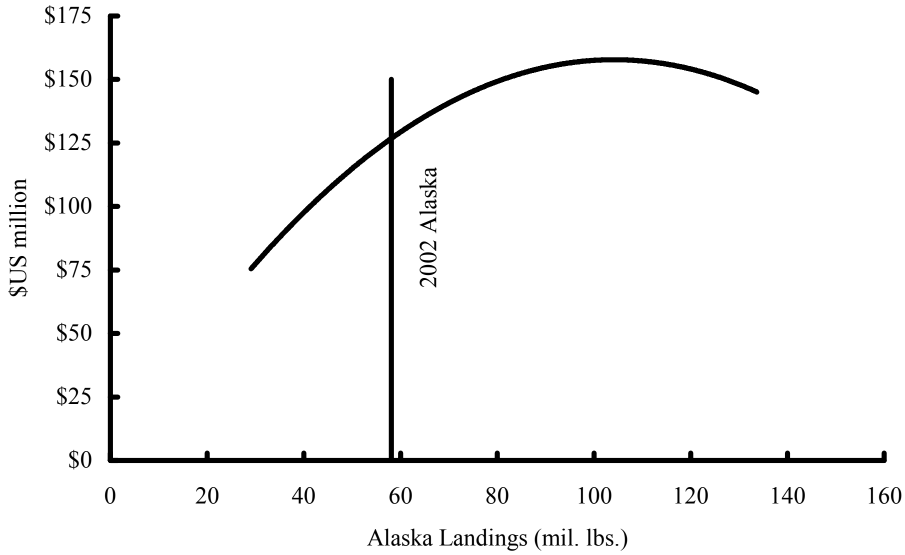

Figure 7. Simulated exvessel revenues ($ million) as a function of Alaskan landings of Pacific halibut.

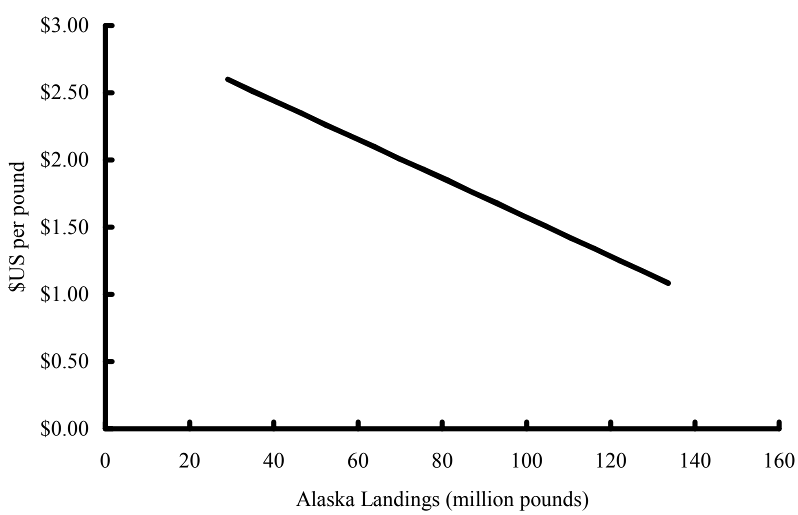

Figure 8. Simulated 2002 exvessel price changes for increased (decreased) Alaska catch levels of Pacific halibut (million pounds).

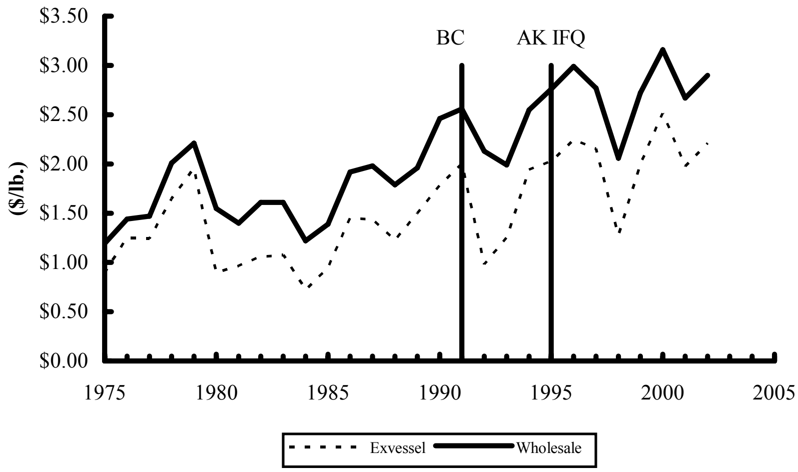

Figure 9. Nominal exvessel and wholesale prices for Pacific halibut in Alaska from 1975-2002 ($/lb).