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Essays on Fish Processors and Catch Shares

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Abstract

Essays on Fish Processors and Catch Shares

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This dissertation studies the potential effects of catch shares on land-based fish processors with a focus on the shoreside Pacific whiting fishery, the first U.S. fishery in which a portion of harvesting quota was allocated to the processing sector upon implementation of individual fishing quotas (IFQs) in 2011. The first chapter utilizes facility-level cost-earnings data to describe processor behavior before and after implementation of IFQs, comparing predicted impacts to observed outcomes. We find evidence of longer seasons under IFQs with higher market ex-vessel prices, which comprised a larger share of the export price. The second chapter analyzes how processors utilize harvesting quota allocations, using several data sources to track processor-owned quota in the whiting fishery during the first seven years of IFQs. Rather than leasing quota holdings in the quota market, we observe processors offering quota at differing

rates to delivering vessels, finding evidence that processors are utilizing their quota allocations in the ex-vessel market to attract deliveries. In the third chapter, we build a novel modelling framework that incorporates processor-allocated harvesting quota in an ex-vessel market with a regionally-differentiated duopsony processing sector, focusing on processor use of quota holdings to secure landings. With this model, we explore how processor-allocated quota can alter ex-vessel market outcomes in equilibrium, providing some insights into the welfare costs and distributional consequences of this policy.

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DEDICATION

To my mom, my biggest fan and greatest supporter

Chapter 1

**CATCH SHARES AND SHORESIDE PROCESSORS:
A COSTS AND EARNINGS EXPLORATION INTO THE DOWNSTREAM SECTOR**

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Marie Guldin and Christopher M. Anderson

Abstract

Although processors can be a significant source of fishery-based employment and rent generation, land-based processors are often not included in analyses of fishery management impacts, generally because no data are available. This article utilizes facility-level, cost-earnings data on shoreside processors in the Pacific whiting fishery to describe behavior before and after rationalization in 2011, where 20% of the harvesting quota was allocated to processors. Predicted effects on processors centered on the potential for season lengthening to lead to increased ex-vessel prices and efficiency gains in the use of processing inputs, like labor and utilities. Data show longer seasons following rationalization, with processors paying higher ex-vessel prices as the ratio of ex-vessel to export prices rose. Estimated changes in efficiency match predictions directionally, but are not statistically significant, which may be due, in part, to the limited number of facilities and the range of other factors from which the impacts of rationalization must be disentangled.

If the industry group is defined, as I think it should be, to include at least the waterfront buyers and processors as well as the fishermen, the economic repercussions [of fisheries regulation] go well beyond those sketched in Gordon's [1954] simplified model. Crutchfield (1956)

¹ <https://www.journals.uchicago.edu/doi/10.1086/698200>

1.1 Introduction

The impact of a policy change or management intervention can be heterogeneous across stakeholder groups; therefore, assessments of the policy effects will vary depending on whose costs and benefits are considered. Fishery management programs, such as catch shares, can affect harvesting behavior along numerous margins, including fishery participation, timing and location of fishing (Gauvin, Ward, and Burgess, 1994), and quality of catch (Geen and Nayer, 1988); all of which may affect fish processor decisions regarding inputs to production, like labor and production supplies, and final product form (Casey et al., 1995). Processors may be a source of significant rents and employment in the local community, even when the harvest sector's rents are dissipated by open access, excessive costs, or depleted stocks (Anderson et al., 2015), and wholesale prices can be twice or more ex-vessel prices (Guldin et al., 2017). Despite this reality, how management changes in the harvest sector affect the processing sector is often not included in the evaluation of those changes. Existing cases generally focus on the ex-vessel market, addressing whether harvesters will benefit from higher prices for their delivered fish. Research on fish processors' input decisions and profitability is typically difficult due to a lack of data on production costs; however, incorporating costs of fish processing into analysis is crucial to understand how fishery management decisions influence optimizing behavior in the processing sector.

The National Marine Fisheries Service (NMFS) has introduced several data collection efforts aiming to fill the information gap for the processing sector. The Fisheries Statistics Division of the NMFS Office of Science & Technology conducts a voluntary nationwide survey of U.S. seafood processors (Survey of Fish Processors) that collects annual data on seafood products and revenues, and in 2014 it added a section to collect product cost data. Additionally, several regional surveys

focus on collecting costs and earnings data from participants of catch share programs. One of the most comprehensive of these regional surveys is the NMFS Economic Data Collection (EDC) survey, which is mandatory for participants of the West Coast Groundfish Trawl Catch Share Program. It captures detailed information on annual costs of production and wholesale earnings at the processing facility level.

This study utilizes the EDC cost-earnings dataset to investigate how the introduction of catch shares into a derby fishery may impact fish processors by examining the implementation of individual fishing quotas (IFQs) in the shoreside Pacific whiting (*Merluccius productus*) fishery, where 20% of the Pacific whiting harvest quota was allocated to eligible processors. We compare observed outcomes to predictions made during the development of the IFQ program discussed in the Final Environmental Impact Statement (FEIS) (PFMC and NMFS, 2010). Rationalization was projected to attenuate the derby and increase the length of the Pacific whiting harvest season, one of the main drivers of potential effects on the processing sector. A longer season was projected to impact processors via consolidation, because less capital would be required to process sector-wide landings. Further, excess capacity among processors could empower harvesters in ex-vessel price negotiations potentially mitigated by the quota allocated to processors. Additionally, season lengthening could allow access to new markets, increasing revenue, and could allow processors to more efficiently use labor and other inputs in the production of Pacific whiting, thereby decreasing costs.

In this article, we consider the effects of IFQs at the sector level by characterizing season length, consolidation, geographical distribution of landings, market ex-vessel price, and final product

types. We supplement this analysis with an exploration of facility-level changes in variable production costs and employment within facilities. We find evidence of season lengthening under IFQs and a decrease in the number of whiting processing firms. We observe higher market ex-vessel prices under IFQs, which comprise a larger share of the export price, indicating that increases could be due to shifts in bargaining power rather than driven by gains in output markets. While the direction of estimated changes in efficiency matches predictions, effects are not statistically significant. This may be due, in part, to the limited number of facilities in the sector and the range of other factors influencing cost measures aggregated over all processing activities within facilities.

The analysis focuses on exploring changes in outcome variables before and after the introduction of IFQs while controlling for key exogenous variables. Ideally, we would include a causal impact analysis where estimated changes were directly attributed to IFQs; however, that is methodologically challenging given the short pre-IFQ time series, the heterogeneity across facilities, and the myriad of other variations from which the effects of IFQs must be disentangled. It is, nevertheless, important to present economically informed descriptions of the observed changes made possible with this unique dataset. Relatively little is known about the facility-level response to IFQ implementation, and the policy monitoring timeline established by the Magnuson-Stevens Fishery Conservation and Management Act (MSA) requires an assessment of a program's effects after the first five years. Where possible, we support the empirical findings with qualitative and narrative interpretations developed through meetings and telephone conversations with processing firm employees who submitted data and other industry members, as well as through the NMFS Pacific Coast Groundfish Fishery Social Study (Russell et al., 2014). This type of

analysis is a key step to a more thorough understanding of the processing sector and its role in fisheries management policy.

1.2 Literature

Analysis of the impacts of catch shares on the processing sector has mainly centered on the ex-vessel market. Homans and Wilen (2005) model a mechanism where, in addition to the potential cost-saving effects of catch shares, product type and market changes generate rent gains to harvesters via higher ex-vessel prices after a transition from derby conditions to IFQ management. Hackett et al. (2005) demonstrate, in a theoretical model rooted in the British Columbia halibut fishery, how these higher ex-vessel prices could create an opportunity for fresh-fish processors to enter the market, further increasing prices. Case studies of specific fisheries illustrate these revenue gains from catch shares. Gauvin, Ward, and Burgess (1994) discuss how IFQs allowed vessels in the South Atlantic wreckfish fishery to optimize the timing of harvest to avoid supply gluts that forced fish into secondary, lower-value markets. A longer fishing season in the British Columbia halibut fishery allowed for more fish to enter the higher-valued fresh markets, increasing ex-vessel prices (Casey et al., 1995). Fishermen in the southern bluefin tuna fishery in Australia were able to more effectively target larger fish under IFQs, which were then supplied to the Japanese sashimi market rather than canneries, garnering a higher ex-vessel price (Geen and Nayer, 1988).

The structure of the ex-vessel market affects how economic rents generated by market and product type changes are allocated across harvesting and processing sectors. McEvoy et al. (2009) and Fell (2009) show that an imperfectly competitive processing sector can negatively influence harvesting sector welfare gains. Additionally, management changes can alter the market structure and

historical division of rents so that both sectors may not be better off. Matulich, Mittelhammer, and Reberte (1996) show that, if processors have less than perfectly malleable capital, season lengthening after implementation of harvester-only IFQs can result in a transfer of processor quasi-rents to harvesters. Extending this analysis, Hackett et al. (2005) find that the transfer of rents may be softened by allowing for a heterogeneous fish processing sector that includes fresh-fish products. Other studies focus on program design and quota allocations. Matulich and Sever (1999) explore how an initial allocation of quota to processors can leave harvesters and processors no worse off; however, market structure is an important determinant of efficiency, distributional changes, and policy feasibility. Milon and Hamilton (2002) compare alternative rationalization models for the Bering Sea and Aleutian Island crab fisheries and discuss potential implications for both harvesters and processors. However, these studies build theoretical models rather than test predictions, likely due to the typical lack of cost data on the shoreside processing sector. There are some exceptions. Fell and Haynie (2013) use state-level cost data to explore how management changes can cause increased spatial competition and higher ex-vessel prices by examining the transition to IFQs in the Alaska sablefish fishery. Matulich and Clark (2003) obtain data on non-fish variable processing costs from a sample of processors in the North Pacific halibut and sablefish fisheries to empirically examine quasi-rents. They find processors to be worse off, on average, after the implementation of IFQs in these fisheries.

This study contributes to the previous literature by leveraging a facility-level dataset to further understand how changes in fisheries management, and in particular the move to catch shares in the shoreside Pacific whiting fishery, could influence the downstream processing sector beyond the ex-vessel market. By focusing on a subset of outcomes and facilities, this article complements

other analyses of the West Coast Groundfish Trawl Catch Share Program. These include the EDC Program's annual report on the first receiver and shorebased processor sector (Guldin et al., 2017), the five-year review of the program (PFMC and NMFS, 2017) mandated by the MSA, and a subsequent study exploring differences in economic outcomes between processors of Pacific whiting and non-whiting groundfish (Guldin et al., 2019).

1.3 Data and Methods

We utilize data from several sources. Sector-level analysis is performed primarily with state fish ticket and biological sampling data from the Pacific Fisheries Information Network (PacFIN). Additionally, product export data were gathered from the U.S. Census Bureau's Foreign Trade Division, accessed through NMFS. The data are at the month level and include the weight and value of frozen Pacific whiting exported from the U.S. in that month.² Reported export quantities may include whiting product landed or processed prior to its export month, as well as imports later resold overseas. The dollar value is based on the transaction price, which includes inland freight, insurance, and other charges incurred placing the merchandise alongside the carrier, but excludes the cost of loading the carrier or any additional costs incurred beyond the export port. We use the information to generate monthly Pacific whiting export prices from 2000-2016.

Our main source of data for the facility-level analysis is the NMFS EDC Program, which collects annual data by fiscal year from all participants of the West Coast Groundfish Trawl Catch Share Program, with data currently available from 2009-2016. Data include annual fish purchases by

² Export data exclude surimi, fresh, and fillet frozen Pacific whiting products, as data are not available for the entire sample.

species and source, fish production and earnings by species and product type, non-fish costs and earnings by category, and employment information (Guldin et al., 2017). Labor expenses are collected by fiscal year; however, additional information on labor, like the number of workers and hours worked, are captured for one week in each month of the fiscal year.³ Non-fish costs (e.g., labor, utilities) and employment information are collected for all operations performed at the facility, including production of non-whiting species.

We supplement our data analysis with qualitative data and in-depth interviews from the NMFS Pacific Coast Groundfish Fishery Social Study (Russell et al., 2014). This formal survey includes semi-structured interviews with representatives at five of the seven major Pacific whiting processing firms and provides information to contextualize patterns in the data.

1.4 Fishery Background

Pacific whiting, sometimes marketed as Pacific hake, is a migratory species that generally spawns in southern waters and migrates northward along the U.S. and Canadian coasts in the spring and summer months (Grandin et al., 2016). The fish are targeted using midwater trawl gear by catcher-processors that both harvest and process fish, and by catcher vessels that harvest fish and deliver to either shoreside processors or at-sea processing vessels called motherships. Harvests are constrained by a total allowable catch (TAC), which is set annually through a bilateral management agreement between the U.S. and Canada known as the Pacific Whiting Treaty. The U.S. Pacific whiting commercial TAC is allocated between the shoreside sector (42%) and the at-sea sectors (58%). Prior to allocation to these sectors, a tribal allocation is subtracted from the U.S. Pacific

³ This follows the U.S. Census Bureau's Annual Survey of Manufacturers (ASM).

whiting TAC (17.5%). If it is determined that the tribal allocation will not be fully utilized, the quota may be reapportioned to the other sectors throughout the season, with this generally occurring on or after September 15th. Stock recruitment is highly variable, and the TAC has fluctuated substantially over the last decade, reaching particularly low levels in 2009-2010 and higher levels in 2014-2016 (Figure 1.1).⁴ In most years, the TAC is almost fully utilized by both the shoreside and at-sea sectors. Recent years are exceptions, as the TAC increased to the highest levels of the past decade. In addition, the Russian Federation imposed a ban on fish imports in August 2014 that remains in effect, and the stock was impacted by anomalous ocean conditions in 2015 where harvesters had difficulty “locating fishable concentrations of whiting” (PFMC, 2016).

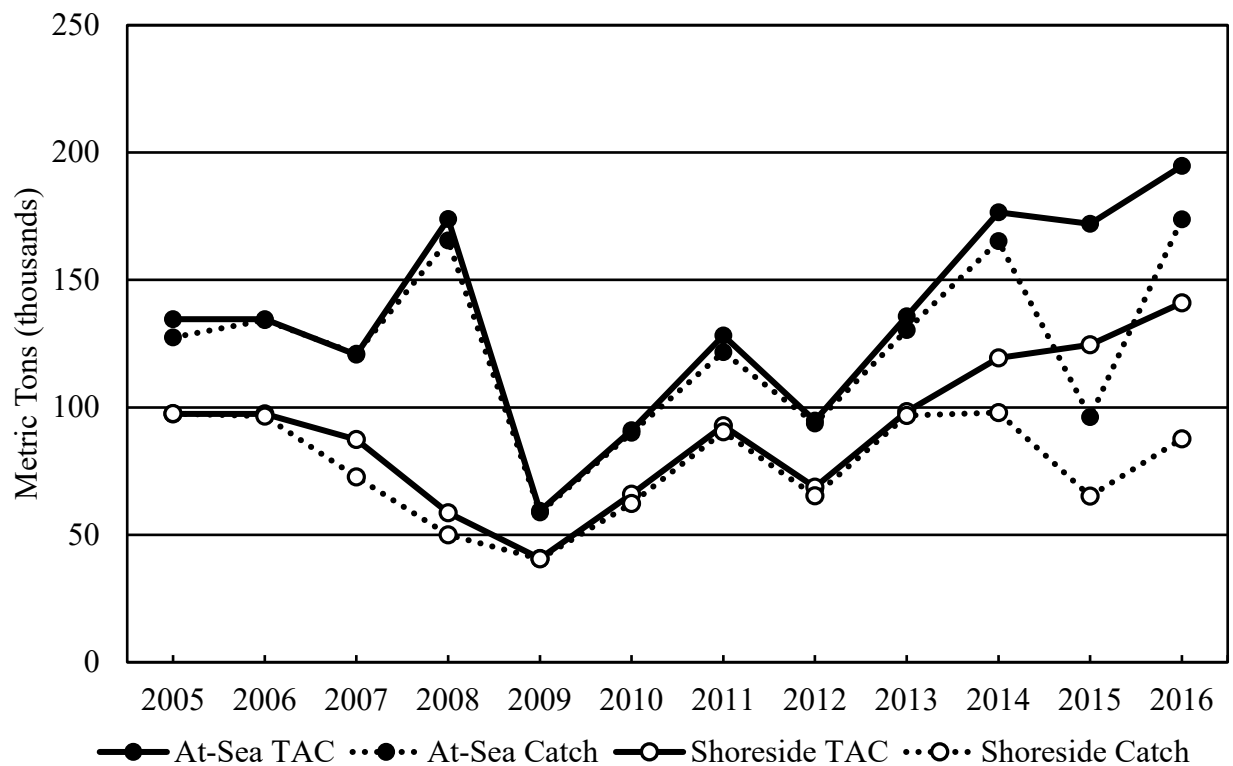


Figure 1.1: Pacific whiting TAC and annual catch by sector and year

⁴ Sector TAC and at-sea harvest data are from Pacific whiting fishery notices: http://www.westcoast.fisheries.noaa.gov/fisheries/management/whiting/whiting_reports_and_rulemakings.html.

Through 2010, Pacific whiting catch was monitored within seasons, and the fishery closed when the sector allocation or a bycatch limit was reached. The resulting fishery was considered a derby, though limited entry and limited capital stuffing contributed to keeping the season several months long. In 2011, the Pacific whiting fishery was rationalized as part of the West Coast Groundfish Trawl Catch Share Program, which consists of an IFQ system for the shoreside sector and cooperative programs for the at-sea sectors.

This article focuses on the shoreside Pacific whiting fishery and associated land-based processors. Seven major shoreside processing firms produced Pacific whiting products in the last decade, with the top three firms purchasing more than two-thirds of the commercial raw fish, on average. Firms can receive fish from the tribal Pacific whiting fishery as well, which is outside the IFQ program. Processing of Pacific whiting is highly mechanized and, after a shift away from surimi in the mid-2000s, the main product type is frozen, headed-and-gutted whiting, which is exported and sold on the global market as a relatively low-value whitefish (PFMC and NMFS, 2010).

The IFQ program included an allocation of 20% of Pacific whiting harvesting quota to eligible shoreside processors. If a firm did not participate in the fishery in the qualifying years from 1998-2004, or did not meet the minimum landings requirements for eligibility, they did not receive a quota allocation.⁵ As processors received a portion of the harvesting quota, it is possible for firms to have additional quota attached to any vessel permits they own and to acquire more quota through purchases in the quota market (from any other quota holder, including harvesters and processors). In the regulatory analysis prepared by the Pacific Fishery Management Council (PFMC) while

⁵ In order to qualify for whiting quota share, a shoreside processor must have received deliveries of at least one metric ton of whiting from whiting trips in any two years from 1998 through 2004.

considering the IFQ program, the shoreside Pacific whiting processing sector was predicted to experience several potential effects: longer seasons in the Pacific whiting fishery, consolidation and higher ex-vessel prices (potentially mitigated by the allocation of harvesting quota to processors), and efficiency gains in the processing of Pacific whiting products (PFMC and NMFS, 2010). In the following sections, we compare each of these predicted impacts with realized outcomes.

1.5 Season Lengthening

Theory and experience suggest that when a fishery transitions from a derby to IFQ management, vessels have more flexibility in when they catch their quota, which can result in a longer season (Gordon, 1954; Casey et al., 1995; Hackett et al., 2005; Birkenbach, Kaczan, and Smith, 2017). We see evidence of this in the Pacific whiting fishery. Over the six years prior to the IFQ program, an average of almost 70% of total harvest was caught by the end of July, while only 35% of total harvest was caught by July after the implementation of IFQs. The number of weeks with Pacific whiting deliveries increased from an average of 20 weeks from 2005-2010 to 27 weeks under IFQs. These longer seasons are characterized by more days of Pacific whiting landings (Figure 1.2) with fewer fish purchased per day by the average processing facility.⁶ Within the seven major processing firms, each facility purchased fish an average of 72 days per season under IFQs, compared to 38 days per season from 2005-2010. National export data indicate that the export season was year-round before and after IFQs, indicating minimal opportunity for endogeneity between export prices and harvest quantities.

⁶ The 2010 shoreside Pacific whiting season was longer than previous years due, in part, to two reapportionments of whiting from the tribal sector in September and October.

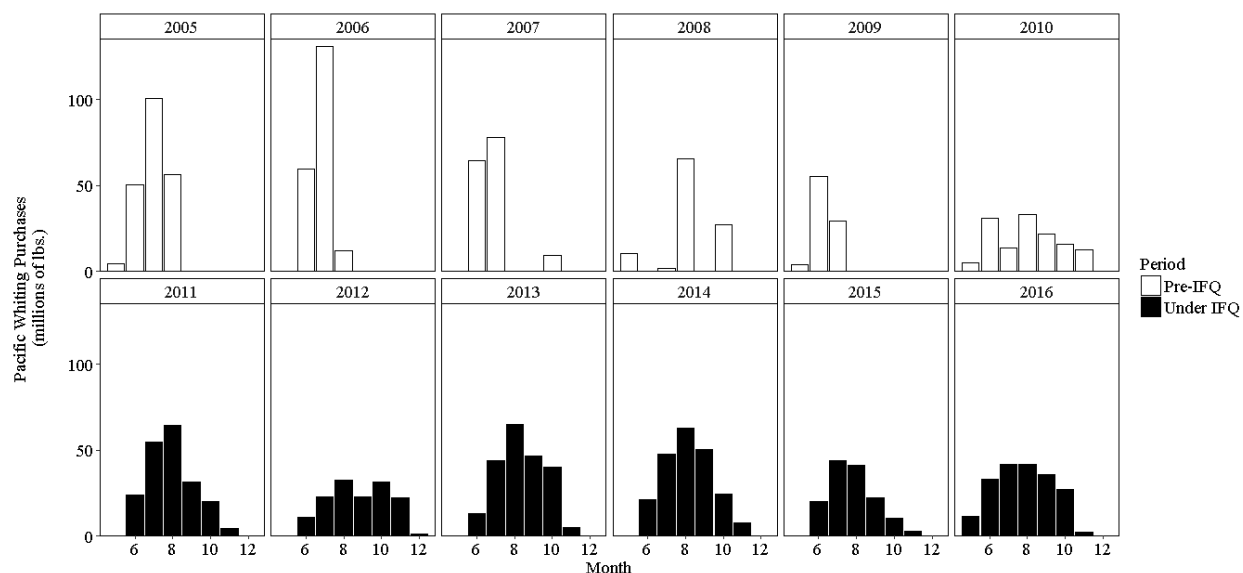


Figure 1.2: Pacific whiting purchases by season

1.6 Consolidation and Location of Landings

The fleet delivering Pacific whiting to shoreside processors experienced consolidation during this period, with the number of vessels falling from an average of 35 participating per year pre-IFQs to 24 under IFQs, as is common when an overcapitalized fishery moves from a derby to IFQs. The remaining vessels each made approximately eight more deliveries, on average, during the season. Consolidation was also projected to occur in the processing sector. The IFQ program was “expected to result in a decline in processing demand, thus reducing the value of processing capital and potentially leading to a contraction in the number of processing companies” (PFMC and NMFS, 2010). The allocation of 20% of the harvest quota to the processing sector was partially justified by the argument that longer seasons with lower daily landings would reduce the processing capacity needed in the sector, “stranding” processing capital, which was both defended (Matulich, 2010) and critiqued (Wilens, 2009) by researchers.

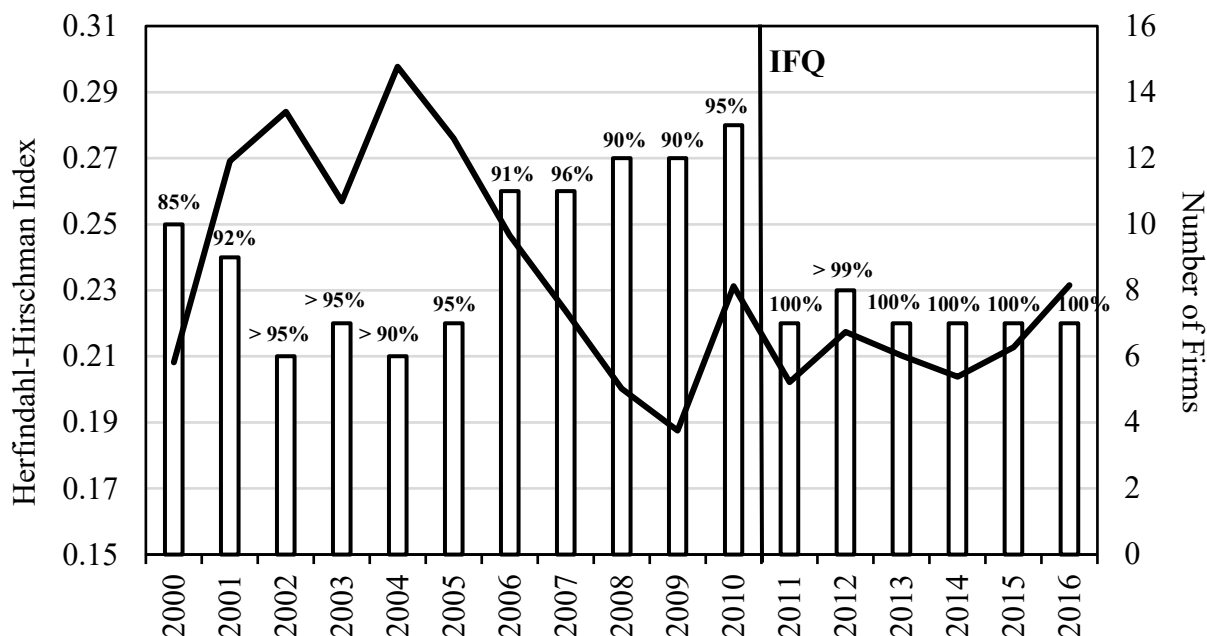


Figure 1.3: Herfindahl-Hirschman index (HHI) of whiting purchases by firm over time (line) and number of firms purchasing Pacific whiting by year (bar) (Note: The percentage above each bar illustrates the percent of whiting purchased by the firms that remained active in 2016. Some percentages are not exact to protect confidential information.)

The number of firms purchasing Pacific whiting has decreased since the implementation of IFQs (Figure 1.3).⁷ To see how this decrease in firms affected industry concentration, we calculate the Herfindahl-Hirschman index (HHI) of the pounds of Pacific whiting purchased by firms.⁸ The most dramatic change in HHI occurred during the mid-2000s when several firms entered the sector, thus decreasing industry concentration (Figure 1.3). While fluctuating with stock and market conditions (e.g., stock migration), the HHI remained relatively steady in the years surrounding the

⁷ Note that not all firms purchase Pacific whiting each year, particularly smaller operations prior to the implementation of the IFQ program.

⁸ HHI is a measure of market concentration calculated by squaring the market share of each firm and summing the resulting numbers. A high HHI indicates a market that is highly concentrated around several firms.

introduction of IFQs (Figure 1.3). Many firms that exited had comparatively small market shares that were then distributed across firms under IFQs, limiting their impact on HHI.

In addition to consolidation, there have been some geographical shifts in Pacific whiting landings over the last decade. The percentage of coast-wide Pacific whiting purchased south of Newport, OR, which was as high as 14% in 2008, dropped to zero under IFQs, and the majority of the buying locations that no longer received Pacific whiting under IFQs were located in California and southern Oregon. This shift in the location of landings is likely due to the opportunities afforded in the California Pacific whiting fishery under derby conditions that were no longer relevant under IFQs. The Pacific whiting fishery in California opens on May 15th, before the primary Oregon and Washington-based season opens on June 15th. Under derby conditions, this allowed vessels, generally those that did not participate in the at-sea fishery, to begin fishing earlier in the shoreside derby. These vessels would deliver to several locations, some of which offloaded fish that was then trucked out of state for processing (PFMC and NMFS, 2010). Fleet consolidation may have influenced this regional shift in landings as about one-third of the vessels that landed fish in California no longer participated in the Pacific whiting fishery. In addition, the majority of these California landings occurred prior to the primary season opening and, without a race to fish under IFQs, vessels and processors have increased flexibility to determine when and where to fish and process, and less incentive to take advantage of the earlier opening in California.

1.7 Ex-vessel Prices

Following the literature on ex-vessel market changes post introduction of IFQs, the FEIS predictions stated that ex-vessel prices for Pacific whiting could increase under the IFQ program

due to revenue gains and could increase or decrease if bargaining power in the ex-vessel market changes. Revenue gains would manifest if the longer seasons allow “new and additional products in the market, and allow specialized niche markets to develop” (PFMC and NMFS, 2010), which could raise ex-vessel prices. Season lengthening and IFQs could also lead to shifts in bargaining power in the ex-vessel market. A full allocation of quota to the harvesting sector was projected to induce a shift of power towards harvesters, increasing ex-vessel prices, but the 20% allocation of quota to the processing sector was established, in part, as an effort to maintain pre-IFQ levels of bargaining power between the two sectors. The competing effects prevent a straightforward prediction, allowing for an interesting exploration into ex-vessel price changes under this IFQ program and the potential mechanisms behind them.

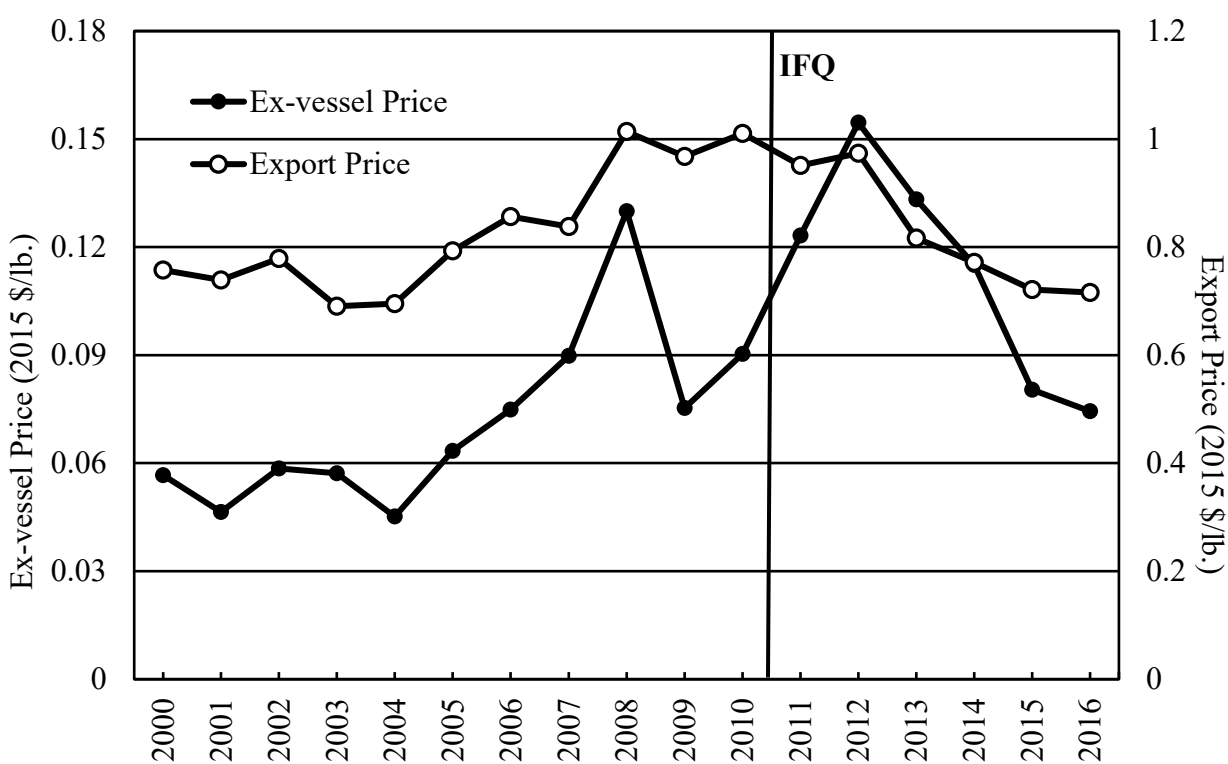


Figure 1.4: Pacific whiting annual ex-vessel prices and export prices

Fish ticket data show that Pacific whiting ex-vessel prices have been generally increasing since 2000 (Figure 1.4). While trends in ex-vessel and export prices track relatively well in pre-IFQ years, their relationship appears altered under IFQs. Export prices were generally decreasing from 2011-2016; however, ex-vessel prices from 2011-2014 were higher than all pre-IFQ years (except 2008). Ex-vessel prices in 2015 and 2016 dropped back to pre-IFQ levels, potentially impacted by factors exogenous to IFQs, such as the Russian embargo beginning in August 2014, anomalous ocean conditions in 2015, reported small fish in 2016, and non-binding TACs in these years.

Table 1.1: Summary statistics for ex-vessel market analysis (2005-2016)

	Pre-IFQ			IFQ		
	Mean	Standard Deviation	N	Mean	Standard Deviation	N
Monthly Pacific whiting ex-vessel price (2015 \$/lb.)	0.0903	0.0280	32	0.1117	0.0291	40
Monthly Pacific whiting export price (2015 \$/lb.)	0.9391	0.1324	32	0.8361	0.1549	40
Monthly ex-vessel price/export price	0.0965	0.0252	32	0.1341	0.0284	40
Fish length (mm)	440.32	22.65	32	399.00	26.19	40
TAC (millions of metric tons)	0.0739	0.0188	32	0.1081	0.0244	40

We explore how the introduction of IFQs into this fishery may have impacted market ex-vessel prices by employing a Chow structural break test while controlling for other important determinants of Pacific whiting ex-vessel prices. Discussions with industry participants indicate that fish size is the largest determinant of Pacific whiting ex-vessel price, which is influenced by the age distribution of the stock. Biological sampling data from PacFIN yield annual median fish

length data as a proxy for the size of fish caught. Monthly Pacific whiting export price is included to control for exogenous changes in world markets. A TAC variable helps to control for the wide variations in TAC over these years. Finally, month-of-season fixed effects are included to control for seasonality. We also weight the regression by the monthly share of annual landings to handle heteroscedasticity. Summary statistics for regression variables before and after the introduction of IFQs are shown in Table 1.1.

Table 1.2: Weighted least squares (2005-2016)

	Ex-vessel Price	Bargaining Power
	Monthly Average Ex-vessel Price (2015 \$/lb.)	Monthly Ex-vessel Price/Export Price
IFQ dummy	0.0682*** (.0102)	0.0739*** (.0132)
Pre-IFQ trend	0.0000 (.0003)	-0.0001 (.0003)
IFQ trend	-0.0004 (.0003)	-0.0001 (.0003)
Pacific whiting export price (2015 \$/lb.)	0.0411 (.0338)	---
Fish length (mm)	0.0003*** (.0001)	0.0003*** (.0001)
TAC (millions of metric tons)	-0.5029** (.2236)	-0.4516** (.2176)
Constant	-0.0620 (.0639)	-0.0310 (.0520)
Month of year fixed effects	Yes	Yes
R-squared	0.7633	0.7118
N	72	72
Weights	Monthly share of annual landings	
Chow test		
H ₀ : Pre-IFQ trend = IFQ trend & IFQ dummy = 0		
F-statistic	36.08	25.25

***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. Standard errors in parentheses.

The regression results (Table 1.2, specification 1) indicate a significant \$0.068/lb. ($p = 0.000$) level shift in the market ex-vessel price upon implementation of IFQs. The price trend is zero in pre-IFQ years and then begins decreasing under IFQs; however, these effects are not statistically significant. These results are robust to falsification tests, where a false treatment was tested in 2007, 2008, 2009, and 2010. In the two subsections below, we explore the potential drivers of this price increase; namely those predicted in the FEIS: product type and marketing effects and shifts in bargaining power.

1.7.1 Product Type and Marketing Effects

Homans and Wilen (2005) develop a theoretical framework illustrating how a shift from derby fishing to IFQs can lead to revenue gains through product type and marketing effects. Case studies provide evidence of these revenue gains in practice, with IFQs allowing for higher-quality products, better market timing, and access to new markets, leading to higher wholesale and ex-vessel prices (Geen and Nayer, 1988; Gauvin, Ward, and Burgess, 1994; Casey et al., 1995). In particular, the increase in ex-vessel price for British Columbia halibut post-rationalization was due to a shift from 42 to 94% production of higher-quality fresh products (Casey et al., 1995). We use EDC data for the years it is available to explore production value and product choices for shoreside Pacific whiting facilities.

The main product types for this sector are headed-and-gutted (H&G), fillet, frozen whole, and other (which includes surimi, unprocessed, and other products). Fillet products have the highest production value per raw input pound (\$0.52), followed by H&G products (\$0.38), frozen whole

products (\$0.31), and other products (\$0.31).⁹ Much of the shoreside Pacific whiting generates H&G products. While the total volume of H&G whiting has increased, on average, since the implementation of catch shares in 2011, these products have comprised a smaller proportion of the sector's total production as the proportions of frozen whole and other products have grown, both of which have lower-value (Figure 1.5). These shifts in product types are due to changes within facilities as well as varying market shares throughout this period, with some facilities comprising larger portions of the sector total in certain years. It is difficult to determine whether these shifts in market share are due to IFQs or some other factor, like changes in the spatio-temporal distribution of whiting from year-to-year. Anecdotal evidence from participants indicates the move towards more frozen whole products is at least partially due to access to a new market in Africa that was exogenous to IFQs. It is also possible that H&G products declined in 2014-2016 due to the Russian embargo if the sector was unable to replace these H&G markets.

To summarize, there is no clear evidence of revenue gains from wholesale markets. There is quite a bit of heterogeneity across facilities in this sector, so the decision making of individual facilities may have been impacted by the introduction of IFQs, but production value per raw input pound for the sector as a whole decreased from an average of \$0.45 pre-IFQ to \$0.35 under IFQs. There are features of the Pacific whiting fishery and transition to IFQs that make this result not entirely unexpected. Some of the other fisheries that experienced wholesale market gains with the transition to IFQs saw large increases in their season length and benefited from access to fresh, or other previously unattainable, markets. Most Pacific whiting product is exported and sold frozen

⁹ The numbers given here are medians of annual sector values from 2009-2016. To convert to production value per raw input pound, we use EDC data on total purchases and production by product to estimate time-invariant product recovery rates for each product type.

in the global market year-round, as Pacific whiting degrades quickly and fresh products have a short shelf life, and the Pacific whiting season under a derby was likely long enough to support a fresh market if there was demand for one.

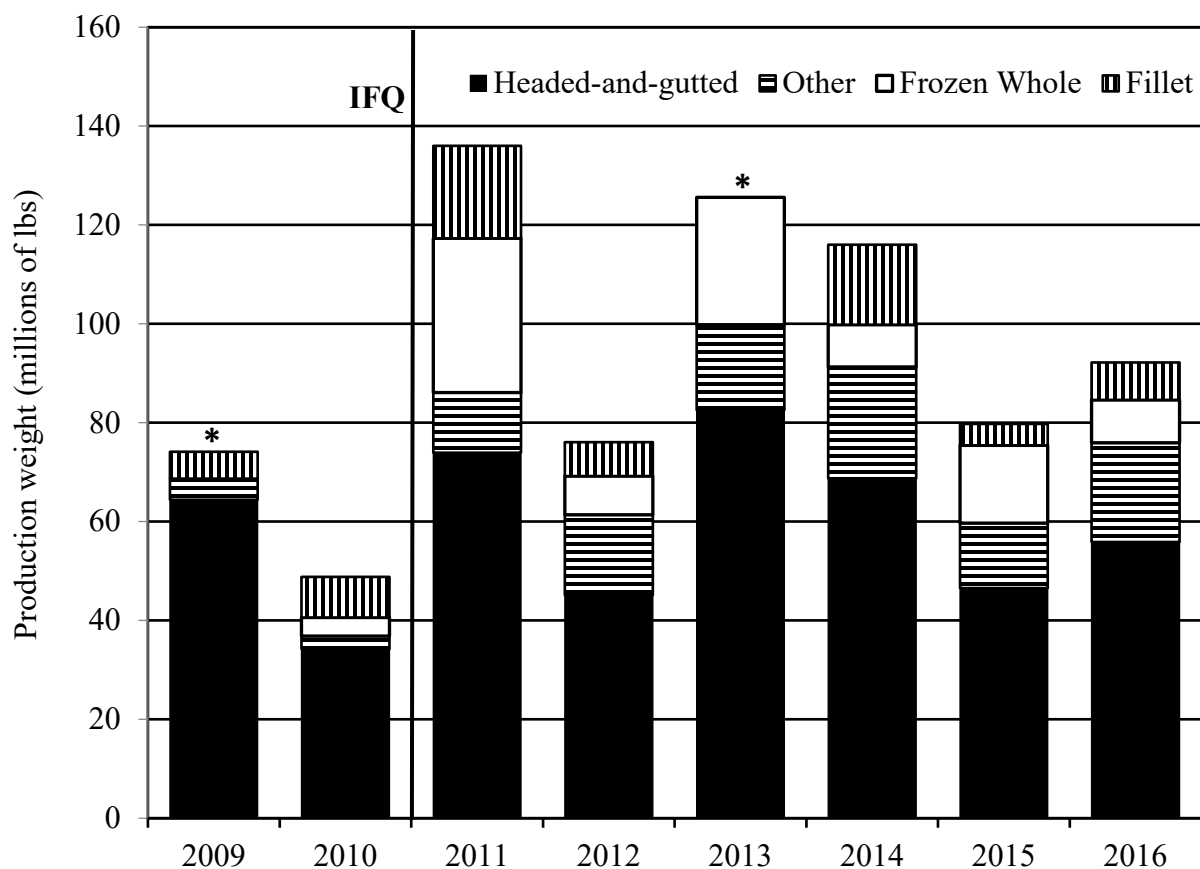


Figure 1.5: Total sector production weight by product type and year

(Note: * indicates years in which values have been suppressed to protect confidential data.)

1.7.2 Bargaining Power

During the development of the IFQ program, it was argued that rationalization could shift bargaining power in the ex-vessel market, due to transition from a race to fish. Unlike derby conditions, vessels have more flexibility in the timing of participation under IFQs; they can choose

not to fish if the market conditions are not optimal. This ability to withhold an allocation from the market could result in a shift in the distribution of rents between harvesters and processors, especially if the processing sector is overcapitalized. Processing facilities could experience excess demand for fish, which could lead them to bid up ex-vessel prices to compete for raw fish (Matulich, Mittelhammer, and Reberte, 1996). These potential shifts in bargaining power were a key consideration in the decision to allocate Pacific whiting harvesting quota to processors (PFMC and NMFS, 2010).

To analyze changes in bargaining power surrounding the implementation of IFQs, we test for a structural break in a proxy measure for bargaining power: monthly ex-vessel price as a share of export price. The results (Table 1.2, specification 2) indicate that the ex-vessel price comprised a 7% ($p = 0.000$) higher share of the export price, on average, under IFQs, with no significant change in the time trends between the two periods.¹⁰ This provides support that a shift in bargaining power towards the harvesting sector could explain some of the increase in ex-vessel prices since 2011. One shoreside processor also provides anecdotal support in the Pacific Coast Groundfish Fishery Social Study:

“There used to be... a mutual reliance... a mutual understanding of the importance of having a [processor], and the importance of having a vessel. Now... [that] aspect of it... has no value. Because there’s no time pressure, there’s no opportunity cost associated with not having a [processor]... Now it’s basically... the fish goes to the highest bidder.”

¹⁰ These results are robust to falsification tests, where a false treatment was tested in 2007, 2008, 2009, and 2010.

1.8 Costs of Production

Despite potential shifts in the ex-vessel market that allow harvesters access to a greater share of production value, one might imagine that longer seasons under the IFQ system could have enabled processing facilities to use their inputs more efficiently (measured as a decrease in cost per processed pound of fish). The FEIS states, “Labor costs per unit of processed fish could be reduced if... deliveries are steadier or made on a predictable basis... Similarly, the physical plant could be more efficiently used if inputs are supplied more regularly. For example, variable inputs like power and water might be obtained at lower cost if demand is more even.” The EDC data allow examination of these potential efficiency gains within facilities, as it includes detailed information on employment and costs of production at processing facilities.

Potential efficiency gains were predicted to occur due to steadier deliveries, and Figure 1.2 provides some evidence of increased uniformity in monthly Pacific whiting landings in seasons under IFQs. However, efficiency in production is more likely tied to daily or weekly landings. To take a closer look at variability in weekly landings, we examine facility-level coefficient of variation (standard deviation/mean) of weekly landings (Table 1.3).¹¹ There is high variation across seasons in the pre-IFQ years with some seasons having a large median coefficient of variation. These are generally seasons with a reapportionment of tribal allocation in September/October, which are characterized by a race for the initial allocation followed by a period of no landings, and then a race to fish the reallocated TAC. Seasons under the IFQ program show

¹¹ A “season” is facility specific and begins on the first day of Pacific whiting landings to that facility and ends on the last day of Pacific whiting landings to that facility.

less variability in weekly landings than pre-IFQ seasons with a reallocation, but exhibit more variability than pre-IFQ seasons with no reallocation.

Table 1.3: Median facility coefficient of variation of weekly Pacific whiting landings

Pre-IFQ						IFQ					
2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
0.29	0.31	1.39	1.61	0.48	1.06	0.74	0.76	0.58	0.57	0.64	0.60

Steadier deliveries were predicted to decrease labor costs per unit of processed fish within processing facilities if worker turnover and overtime hours were reduced, or if processing facilities were better able to utilize their capital resources (PFMC and NMFS, 2010). We explore annual hours worked per pound of total fish output for all operations at facilities using a balanced panel of eight whiting facilities. Most whiting facilities have activities outside the IFQ program, processing species like crab, shrimp, and sardines, and we do not expect IFQs to have led to meaningful efficiency gains in the production of these species. However, the IFQ program includes non-whiting groundfish in addition to Pacific whiting, so it is likely the introduction of IFQs affected the production of non-whiting groundfish. Therefore, we examine whiting facilities with significant non-whiting groundfish operations separately from those that do not. We also include non-whiting groundfish facilities with no whiting operations as another comparison point.

Average annual hours worked per pound of total fish output decreased under IFQs for whiting facilities, and the trend is even clearer if whiting processing facilities are separated based on their

specialization (Table 1.4).¹² Whiting facilities with no significant non-whiting groundfish production require fewer hours worked per pound of output under IFQs than in the two pre-IFQ years. This is not the case for whiting facilities with significant non-whiting groundfish operations and for non-whiting groundfish facilities, where trends are increasing, on average, but generally less clear.¹³

Table 1.4: Facility average annual ratio of hours worked and pounds of total fish output

Hours/Thousand Output Lbs.	N	Pre-IFQ		IFQ					
		2009	2010	2011	2012	2013	2014	2015	2016
Whiting facilities	8	11.92	13.06	11.35	9.99	9.52	8.49	10.21	10.98
Without non-whiting groundfish production	5	11.36	12.16	9.13	7.41	8.34	7.12	8.58	7.73
With non-whiting groundfish production	3	12.86	14.56	15.05	14.29	11.50	10.78	12.92	16.41
Non-whiting groundfish facilities	3	33.83	25.38	30.70	37.30	32.66	31.03	31.65	32.30

To summarize, there is some evidence of steadier deliveries and decreased labor hours per output within facilities, which were predicted drivers of efficiency gains. To further assess potential efficiency gains within facilities, we examine costs per processed pound of fish for all operations at a given facility with a balanced panel of eight whiting facilities, focusing on labor and utilities expenses per FEIS predictions.¹⁴ Labor and utility costs per processed pound decreased, on

¹² Annual hours worked are extrapolated from data collected on the EDC survey on hours worked for one week in each month, under the assumption that this week is representative of the month.

¹³ Consistent trends are observed for all categories when examining annual hours worked per pound of total fish inputs.

¹⁴ The utilities expenses that are collected on the EDC survey include electricity, water, gas (propane and natural), and sewer, waste and byproduct disposal.

average, from the pre-IFQ period to the IFQ period (Table 1.5), indicative of potential efficiency gains induced by IFQs. Facility costs per processed pound vary depending on a number of operational characteristics, including what species are produced, what product types are generated, and the level of inputs required to produce a given product type. We also observe decreased labor and utility costs per input pound, on average, from the pre-IFQ period to the IFQ period (Table 1.5), which provides some indication that gains in efficiency may be occurring within product types. To explore this further, we employ a regression framework with best available controls. Again, we separate whiting facilities based on specialization in an effort to focus on changes specific to Pacific whiting production.

The variables of interest are a dummy variable for years under the IFQ program and the interaction of this variable with a dummy variable indicating whether the facility has significant non-whiting groundfish operations. Given that facilities produce a number of species and product types that have different costs of production, changes in the relative contribution of individual species and product types to a facility's overall operations can alter efficiency. Therefore, we include two sets of variables to control for shifts in production of species groups and product types. Both sets of variables separate total production into several categories that group species and product types with similar costs of production, while being broad enough to accommodate the fairly limited number of observations. One set of variables includes the share of total production comprised of non-whiting groundfish species and the share of other species, where the omitted category is the share of total production comprised of Pacific whiting. The second set of variables includes the share of total production comprised of H&G and filleted whiting, the share of frozen pelagic

species,¹⁵ and the share of other frozen products, where the omitted category includes all other products, such as processed fresh, canned, bait, and fish meal.¹⁶ We separate frozen products into these categories as pelagic species, like whiting, are more likely to be frozen whole, while other species, like sablefish, are more likely to be processed prior to freezing.

Table 1.5: Summary statistics for cost analysis (fiscal years 2009-2016)

	Pre-IFQ			IFQ		
	Mean	Standard Deviation	N	Mean	Standard Deviation	N
Labor costs per processed pound (2015 cents/lb.)	17.90	9.56	16	16.83	7.95	48
Labor costs per input pound (2015 cents/lb.)	11.75	5.19	16	11.22	5.79	48
Utility costs per processed pound (2015 cents /lb.)	4.07	3.05	16	3.61	1.99	48
Utility costs per input pound (2015 cents /lb.)	2.59	1.26	16	2.36	1.18	48
Non-whiting groundfish share	0.1215	0.1626	16	0.0553	0.0715	48
Other species share	0.4591	0.2381	16	0.3938	0.2796	48
H&G/filleted Pacific whiting share	0.2526	0.2358	16	0.3410	0.2165	48
Frozen pelagics share	0.1886	0.3074	16	0.2093	0.2214	48
Frozen other share	0.1651	0.1356	16	0.1680	0.1621	48
Sector Pacific whiting purchases (thousands of metric tons)	51.48	11.56	16	82.32	15.52	48
Hourly wage (2015 \$)	12.72	0.6432	16	12.68	0.3228	48

* Share indicates share of total annual processed fish weight. Non-whiting groundfish share and other species share indicate proportion of production by species group. Remaining share variables indicate proportion of production by product type.

¹⁵ Pelagic species include Pacific whiting, sardines, anchovies, and mackerel.

¹⁶ We do not include a control for fresh products, as this variable was highly correlated with the share of total production comprised of non-whiting groundfish.

The large increases in TAC over this period could have led to economies of scale, so we control for total sector purchases.¹⁷ We also include a proxy for fish processing worker wages from the Bureau of Labor Statistics¹⁸ to control for changes in labor expenses due to trends in state wages. Facility fixed effects control for fundamental differences across facilities such as size, operations, and location. Summary statistics for regression variables before and after the introduction of IFQs are shown in Table 1.5.

The regression results are shown in Table 1.6. Specifications 1 and 3 include control variables for changes in Pacific whiting product types, assuming that any shifts over this period are exogenous to the introduction of IFQs. There is little evidence to indicate that observed shifts in whiting product types are associated with IFQs, therefore specifications 1 and 3 are our preferred models. However, as a comparison, we also include specifications 2 and 4, which do not explicitly control for changes in Pacific whiting product types and, therefore, associate these changes with any effects observed in the IFQ dummy.

The results (Table 1.6) indicate that some of the control variables are important for explaining variation in labor and utility cost per processed pound. The share of total production that is non-whiting groundfish has a large, positive, and significant impact on labor costs per processed pound, as non-whiting groundfish filleters are more skilled and the fishery has a higher value per pound than Pacific whiting. The share of total production consisting of frozen products from non-pelagic species also has a positive and significant impact on overall labor costs and utility costs per processed pound, as these products are more likely to be processed and then frozen, requiring more

¹⁷ We use total sector purchases rather than TAC, as the TAC was not binding in 2014-2016.

¹⁸ We use Washington and Oregon annual average wages for meat, poultry, and fish cutters and trimmers.

labor and other inputs. Facility fixed effects are significant ($p < 0.006$) in both regressions, and have a range of 23.39 and 8.47 cents/lb. for labor and utility costs, respectively. These are not shown for confidentiality reasons, but their significance and range indicate that per-pound costs vary considerably across facilities based on their characteristics.

Table 1.6: Ordinary least squares (fiscal years 2009-2016)

	(1)	(2)	(3)	(4)
	Labor Cost per Processed Pound (2015 cents/lb.)		Utilities Cost per Processed Pound (2015 cents/lb.)	
IFQ dummy	-1.78 (1.75)	-2.32 (1.92)	-1.15 (.6985)	-1.25* (0.7120)
IFQ*Non-whiting groundfish dummy	8.53* (4.91)	8.85* (4.86)	2.25** (1.00)	2.27** (1.01)
Non-whiting groundfish share	58.12*** (20.63)	58.25*** (19.97)	5.48 (3.71)	5.83* (3.16)
Other species share	-2.37 (4.25)	-3.80 (6.07)	0.0099 (1.42)	0.2015 (2.07)
H&G/filleted Pacific whiting share	-2.74 (6.44)	---	-1.45 (2.88)	---
Frozen pelagics share†	-0.1864 (6.10)	4.18 (6.09)	-0.5483 (2.27)	0.5216 (2.02)
Frozen other share	15.35** (6.06)	18.28*** (6.18)	6.46*** (2.23)	7.31*** (1.77)
Sector Pacific whiting purchases (thousands of metric tons)	0.0481 (.0333)	0.0486 (.0335)	0.0104 (.0104)	0.0098 (.0108)
Hourly wage (2015 \$)	2.12* (1.21)	2.14* (1.19)	---	---
Constant	-5.52 (15.03)	-5.44 (15.12)	8.16*** (.7381)	8.08*** (.7973)
Facility fixed effects	Yes	Yes	Yes	Yes
R-squared	0.8480	0.8489	0.8193	0.8166
N (observations)	64	64	64	64
N (facilities)	8	8	8	8

***, **, and * indicates significance at the 1%, 5%, and 10% levels, respectively. Standard errors in parentheses.

† Frozen pelagics share excludes Pacific whiting in specifications 2 and 4.

Examining the variables of interest for whiting facilities with no substantial non-whiting groundfish operations, the results (Table 1.6, specifications 1 and 3) show that average facility labor and utility costs per processed pound decreased under IFQs by 1.78 cents/lb. ($p = 0.11$), or 8.7%, and 1.15 cents/lb. ($p = 0.14$), or 18%, respectively, but neither change is statistically significant. While also not statistically significant, the estimated changes in labor and utility costs per processed pound move in the opposite direction for whiting facilities with non-whiting groundfish operations, with a 6.75 cents/lb. ($p = 0.14$), or 17% increase, and a 1.1 cents/lb. ($p = 0.17$), or 20% increase, in labor and utility costs per processed pound for the average facility, respectively.¹⁹ The coefficients on the variables of interest in specifications 2 and 4, where the IFQ dummy variable encompasses Pacific whiting product type shifts, are similar to specifications 1 and 3, but larger in magnitude and weakly significant in the case of utility costs per processed pound. This follows intuition, given the increased proportion of lower value products, like frozen whole, which are likely less costly to produce per pound.

While the changes in labor and utility costs per processed pound directionally match predictions, the efficiency gains are either weakly or not statistically different from zero. It could be that predicted efficiency gains are longer-term impacts that will be realized as processors decapitalize their Pacific whiting assets or adjust their operations to utilize those assets with the production of other species. It is also possible that characteristics of the data are hindering the ability to determine a significant effect. Given the small number of heterogeneous facilities, the breadth of operations at these facilities and the short pre-IFQ period that was characterized by considerably lower TAC, our estimator may lack sufficient power to identify effects that may exist due to the introduction

¹⁹ These values are calculated by summing the coefficients for the IFQ dummy variable and the IFQ and non-whiting groundfish dummy interaction. The p-value is from the Wald test on the sum of the coefficients.

of IFQs. In addition, while we try to control for other species and product types processed at these facilities, it could be that the aggregated cost information is masking impacts specific to Pacific whiting production.

1.9 Conclusion

This article explores changes to the West Coast shoreside Pacific whiting processing sector in the eight years surrounding the implementation of a transferable quota program. We observe consolidation in the sector and a geographic shift in landings, as the small California portion of the fishery is no longer active. The data reflect that the season lengthened as a result of curtailing the derby. However, the whiting fishery did not experience a corresponding shift to higher wholesale prices, as observed in other transitions to catch shares. Instead, higher ex-vessel prices comprise a larger share of the export price, indicating potential shifts in bargaining power due to increased harvester flexibility in negotiating and timing deliveries with processors.

Utilizing a unique cost-earnings dataset, this descriptive analysis goes beyond the ex-vessel and export markets to explore the costs of production within shoreside fish processing facilities. Variable costs per processed pound, particularly expenses on labor and utilities, were predicted to decrease due to the effects of season lengthening. However, we find that processor characteristics and the production of higher-cost products, like non-whiting groundfish species, are more important determinants of efficiency within facilities. Decreases in the costs of labor and utilities per processed pound of 8.7% and 18%, respectively, were observed under the IFQ program, but were not statistically significant.

There are numerous extensions to this research within the context of the West Coast groundfish trawl fishery. Guldin et al. (2019) examines measures of individual profitability, such as net revenue, as well as other processor outcomes before and after the introduction of IFQs and compares Pacific whiting processors to non-whiting groundfish processors. The non-whiting groundfish fishery offers an interesting comparison to Pacific whiting, as it has a more extensive market for fresh products and was managed by bi-monthly landings limits prior to IFQs (Warlick, Steiner, and Guldin, 2018) that prevented derby conditions. We are also currently analyzing the allocation of Pacific whiting harvesting quota to the processing sector, which is particularly important, as this policy may be included in other fishery management programs in the future.

Analysis of the potential impacts of IFQs on the fish processing sector has been, and will continue to be, limited by availability of information. The efforts of NMFS to collect more data on this sector will help support future research. Even with thorough, comprehensive data on processing sector costs and earnings, limitations still exist. In the Pacific whiting fishery, the industry is comprised of a small number of participants, and the timeframe of the data is currently only eight years; therefore, causal inference can be constrained by regression power. In addition, the pre-IFQ cost data contain only two years, during which Pacific whiting TAC levels were unrepresentatively low. The ability to analyze stranded capital within facilities, a focus during the design of this IFQ program, is difficult with little information on processing lines, machinery, and capacity. This limits the scope of our analysis and makes formal impact evaluation challenging. Nevertheless, we argue that this initial examination of a new IFQ program with a federally mandated data collection is important in an iterative and adaptive management context. Research on the processing sector

is required to better inform decision makers regarding potential consequences of catch share programs and in what capacity this sector should be included in these programs.

Chapter 2

**SHORESIDE PROCESSOR USE OF HARVESTING QUOTA:
EVIDENCE FROM THE PACIFIC WHITING FISHERY****Abstract**

Catch shares aim to increase net economic benefits in fisheries and resulting rents are distributed across diverse participants within and across the harvest and post-harvest sectors. The initial allocation of property rights for catch share programs can be important for the eventual distribution of rents and for mitigating negative impacts against certain groups. In most IFQ programs, quota is initially allocated to vessel permit owners; however, in one of the most recent IFQ programs in the U.S., fishery managers implemented the unprecedented policy of allocating a portion of the harvesting quota to land-based fish processors in the shoreside Pacific whiting fishery in 2011. In this study, we use several unique data sources to track processor-owned quota in the whiting fishery during the first seven years of the IFQ program to assess how processors utilize their harvesting quota allocation, which can have distributional and efficiency implications. Rather than leasing quota holdings in the quota market, we observe processors offering quota at differing rates to delivering vessels, finding evidence that processors are utilizing their quota holdings in the ex-vessel market to attract deliveries. We also find some evidence that processors charged a fee per pound of quota transferred through discounted ex-vessel prices. These impacts of quota in the ex-vessel market were only identified in the first three years of the program when the TAC was binding. This study provides the first empirical analysis of processor-allocated harvesting quota, furthering our limited understanding of this policy.

2.1 Introduction

At the outset of an individual fishing quota (IFQ) program, fishery managers must determine an appropriate method of initially distributing harvesting rights to fishery participants. Theory suggests that, if quota is transferable, the resource rent will be maximized independent of the initial allocation process (Montgomery, 1972). In reality, this may not always be the case if, for example, there are high transactions costs associated with quota transfer (Liebcap, 2007). In addition, initial quota allocations can impact the distribution of the resource rent within the fishery. Thus, the process of assigning initial quota allocations can be contentious and policymakers have used allocations to address concerns or meet goals associated with distributional outcomes under IFQs. In most IFQ programs, quota is initially allocated to vessel permit owners based on historical participation in the fishery as a means of compensation for existing investments that may become redundant under IFQs. However, in one of the most recent IFQ programs in the U.S., fishery managers implemented the unprecedented policy of allocating a portion of the harvesting quota to land-based fish processors in the shoreside Pacific whiting fishery in 2011 (PFMC and NMFS, 2010; Warlick, Steiner, and Guldin, 2018). This paper provides the first empirical analysis of this policy using several unique data sources to track processor-owned quota in the whiting fishery during the first seven years of the IFQ program. We examine how processors utilize harvesting quota allocations, which can have important implications for ex-vessel market dynamics and efficiency (Guldin, Chapter 3), furthering our limited understanding of the potential effects of allocating harvesting quota to processors.

The question of whether or not fish processors should also be compensated for redundant investments or stranded capital arose around the time of the moratorium on IFQ programs in the

U.S. from 1996 to 2002, which was established in part due to concerns over how IFQs may affect the distribution of rents within fisheries. Matulich, Mittelhammer, and Reberte (1996) model the transition to IFQs and find that processors can be adversely impacted by IFQs, particularly from a pre-IFQ race-to-fish. As seasons lengthen under IFQs, processors may be overcapitalized during the transition as daily throughput decreases, leading to excess demand for raw fish that results in increased ex-vessel prices (Matulich, Mittelhammer, and Reberte, 1996). To address this, several alternative initial quota allocations were proposed for consideration, including a ‘one-pie split allocation’ where processors are allocated a share of harvesting quota and a ‘two-pie allocation’ where processors are allocated separate processing quota (Matulich, Mittelhammer, and Reberte, 1996; Matulich and Sever, 1999). These policies were, and continue to be, met with resistance as stakeholders, researchers, and policymakers expressed a number of concerns, including whether such policies are appropriate or necessary (Young, 2004; Wilen, 2009; Fell and Haynie, 2010) and whether they promote anticompetitive behavior and increase market power in the processing sector (Wilen, 2008; Powell, 2004; Halvorsen, 2004). In 2004, the Magnuson-Stevens Fishery Conservation and Management Act was amended to allow implementation of a two-pie allocation in the Bering Sea and Aleutian Islands crab fisheries but prohibited the introduction of this policy in any other fishery (H.R.2673).²⁰ At the same time, discussions of rationalizing the West Coast groundfish trawl fishery, including the shoreside Pacific whiting fishery, began. The processing sector sought a quota allocation citing concerns of stranded capital and shifts in bargaining power in the ex-vessel market that could arise under a transition from derby fishing to a harvester-only IFQ program. Given the prohibition of the two-pie allocation, a one-pie split allocation was favored and 20% of the Pacific whiting harvesting quota allocation was initially allocated to

²⁰ <https://www.congress.gov/bill/108th-congress/house-bill/2673>

eligible processors based on historical purchases of whiting in the ex-vessel market (PFMC and NMFS, 2010).

Fishery participants with harvesting quota holdings own a portion of the catch, which is valuable if quota is scarce. In single-species fisheries like the Pacific whiting fishery, this generally occurs when the total allowable catch (TAC) is fully utilized and acts as a binding constraint. Harvesters extract rent from quota holdings by fishing quota pounds or by leasing pounds in the quota market to participants with a higher value. Shoreside processors, on the other hand, can only extract rent from harvesting quota by transferring quota holdings to vessels. One way to do this is in the quota market, transferring seasonal ownership of quota pounds to harvesters in exchange for a lease fee (Matulich and Sever, 1999; Milon and Hamilton, 2002). If the quota market is efficient, the processor receives the market equilibrium quota price for each pound of quota leased. Prior to the implementation of IFQs in the Pacific whiting fishery, processors stated that they did not intend to lease quota in the quota market, planning instead to use quota holdings to secure landings in the ex-vessel market: “Our interest in quota is not to lease it out as a revenue source. We are processors, not quota brokers. Our intent is to use quota directly allocated to processors as an enticement to vessels to deliver to historical processors” (WCSPA, 2007). This method of informal contracting involves trading quota pounds for delivered fish. Processors may also indirectly price quota transferred to delivering vessels through discounted ex-vessel prices (less some contracting premium). Whether a processor prefers to contract their processor-owned quota or to lease it in the quota market depends on the relative values of the market quota price and the marginal profit from processing a pound of fish, and on how useful processor-owned quota is at enticing landings.

Using data from 2011-2017 in the shoreside Pacific whiting fishery, we find evidence that processors are utilizing their quota holdings in the ex-vessel market by informally contracting with delivering vessels, and estimate that transferring one additional pound of processor-owned quota resulted in an average of 1.03 additional pounds of whiting delivered. We also find some evidence of discounted ex-vessel prices, with processors charging an estimated average contracting premium of 1.5 cents per pound of quota transferred, which was half of the average market quota price. These impacts of quota in the ex-vessel market were only identified in the first three years of the program when the TAC was binding, offering some indication that the value and usefulness of a quota allocation decreased as the amount of unharvested TAC increased in the fishery.

2.2 Model

Before empirically examining the use of processor-owned harvesting quota in the shoreside Pacific whiting fishery, we develop a simple model to create some general intuition about how processors can utilize a harvesting quota allocation and the conditions under which these respective strategies are preferred in a fishery. In this study, we consider two different quota utilization strategies and the marginal profit a representative processor earns from each.

The first strategy, denoted the *lease option*, is for the processor to lease processor-owned quota in the quota market. The processor earns a marginal profit of p^q on each leased quota pound, where p^q is the market quota price. We assume that this is an arm's-length transaction, where the processor transfers ownership of that quota for the season and must compete for deliveries of this quota as they would harvester-owned quota. If harvesters are the primary buyers of quota in the

quota market, the market quota price will reflect their value of a unit of quota, i.e., the marginal profit from harvesting a pound of whiting.

The second strategy, denoted the *contract option*, assumes that the processor uses quota in ex-vessel market negotiations with delivering vessels. The marginal profit from contracting is $(\alpha p^w - p_c^x - c)\Delta q$, where α denotes the product recovery rate, p^w denotes the first-wholesale price the processor receives for sale of fish products, and c denotes the marginal cost of processing a pound of fish (assumed to be constant). Δq represents the impact of a processor-owned quota pound on vessel supply, where $\Delta q \geq 0$. If $\Delta q = 1$, then offering an additional unit of quota to a vessel increases their delivery by one pound, indicating a one-to-one relationship between contracted quota pounds and delivered pounds. How responsive vessel supply is to an additional contracted quota pound will depend on conditions in the fishery, including how valuable an additional quota pound is to a vessel, market power and structure, and ex-vessel price. The price offered to vessels under this contract option is denoted as p_c^x , where $p_c^x = p^x - \frac{p^c}{\Delta q}$ (the ex-vessel price, p^x , discounted by a per-pound contracting premium, p^c , on each processor-owned quota pound transferred to the vessel).

The processor will choose to contract over lease if the marginal profit from contracting is greater than the marginal profit from leasing. This occurs when the change in quantity associated with contracting a pound of quota is greater than the ratio of the market quota price and the marginal profit of processing a pound of whiting.

$$(\alpha p^w - p_c^x - c)\Delta q > p^q$$

$$\Delta q > \frac{p^q}{\alpha p^w - p_c^x - c}$$

As the market quota price increases relative to the marginal processing profit, a larger increase in quantity landed is required for the processor to choose contracting over leasing. This is more likely to occur in fisheries where harvesters have more power in the ex-vessel market, which would allow them to secure higher ex-vessel prices, increasing vessel margins (and thus the market quota price) and decreasing processor margins. As processors gain more power in the ex-vessel market, processor margins increase relative to harvester margins and contracting will be preferred. In the most extreme case of a monopsony processing sector, contracting and leasing are the same. The processor can capture the full market quota price in the contract premium and $\Delta q = 1$. In some fisheries, it may be optimal for processors to both contract and lease processor-owned quota. If processors face daily (or weekly) capacity constraints or increasing marginal costs, processors may prefer to contract earlier in the season to help reach optimal daily (or weekly) throughput, and then switch to leasing later in the season if they have excess quota. While this simple model does not explicitly capture this scenario and some of the other complexities that may be present in a fishery, it offers insight by focusing on several key dynamics associated with the decision of how to utilize processor-owned harvesting quota.

In the next section, we apply this framework to the shoreside Pacific whiting fishery. Using detailed data from fish tickets, quota transactions, and processor-level cost-earnings surveys, we can estimate these parameters to examine how processors are using their allocation of harvesting quota in this fishery.

2.3 Case Study – Shoreside Pacific Whiting Fishery

2.3.1 Fishery Description

The U.S. shoreside Pacific whiting fishery is one of several fisheries along the West coast of the U.S. and Canada that targets Pacific whiting (*Merluccius productus*), also known as Pacific hake. In 2011, the West Coast Groundfish Trawl Catch Share Program established an IFQ system in this fishery, where the annual overall Pacific whiting quota allocation is determined by a total allowable catch (TAC) set each season. The fishery is characterized by nearly binding TAC in most years. Historically, an average of 94% of the TAC was caught from 2005-2010 (Guldin and Anderson, 2018), and an average of 97% of the TAC was caught under the first three years of the IFQ system (2011-2013). Utilization of the TAC has fallen in recent years though (Figure 2.1) due to various factors that have impacted whiting markets and fishing conditions. Russia, a previously large importer of Pacific whiting products, established an embargo on food items from the U.S. and other countries in August of 2014 that is still in effect, which forced processors to seek other markets for whiting products. In addition, El Nino conditions paired with “the Blob,” a mass of warm water along the coast, seem to have impacted fishing conditions in 2015, where the industry struggled to locate aggregations of whiting (PFMC, 2016), catching only 52% of the overall allocation. The TAC has also increased substantially in recent years due to estimations of large 2010 and 2014 cohorts in the stock assessment (Berger et al., 2017). As we examine how processors use their harvesting quota allocation in this fishery in the following sections, we hypothesize that quota will be less valuable to processors in years when the TAC is more slack, as quota is not as scarce during these seasons.

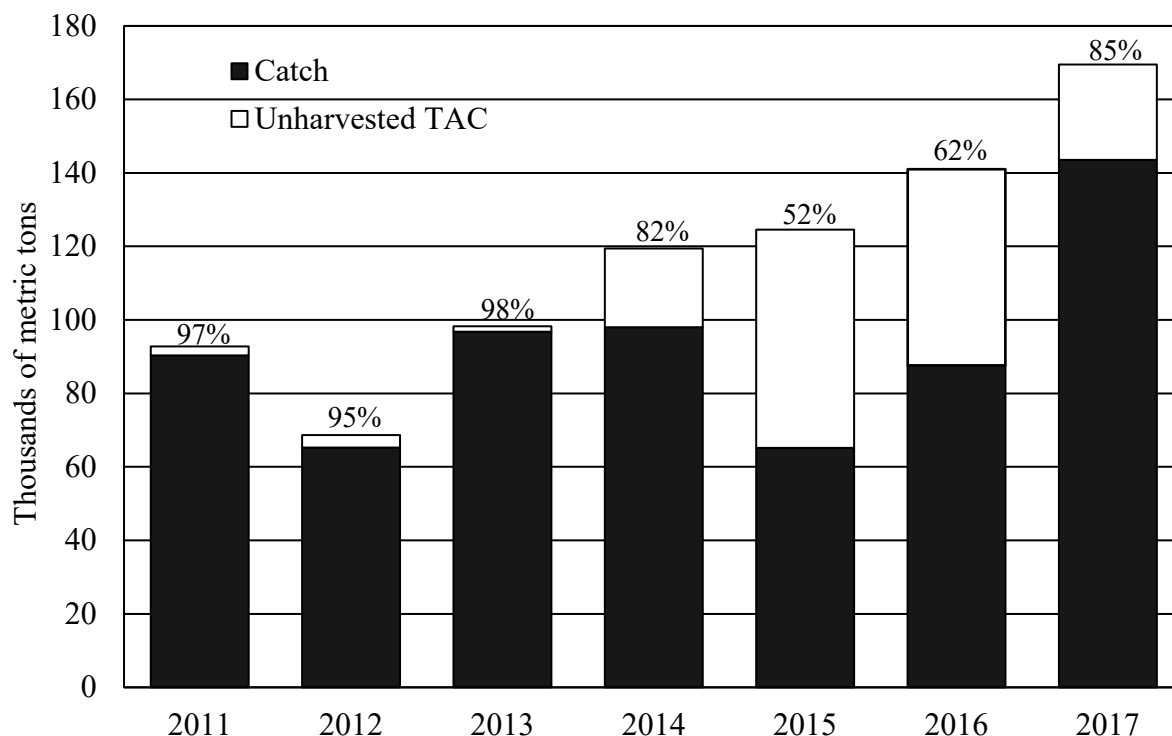


Figure 2.1: Catch and unharvested TAC (thousands of metric tons) from 2011 to 2017. Utilization rates are listed above each bar.

In the shoreside Pacific whiting fishery, 24 vessels on average participated each season from 2011 to 2017, and there were seven active processors under IFQs. The initial allocation of Pacific whiting quota in the IFQ system was such that 80% of the overall Pacific whiting allocation was distributed to vessel permit owners based on historical deliveries during 1994-2003 and the remaining 20% was allocated to eligible processors (Table 2.1).²¹ Processor eligibility and initial allocation percentages were determined by historical purchases of the harvest during a set of control dates (1998-2004) (Warlick, Steiner, and Guldin, 2018).

²¹ In this fishery, processors are sometimes comprised of multiple processing facilities; therefore, we use ownership information to identify linked facilities and aggregate data for this study, such that the unit of analysis is processor.

Table 2.1: Processor initial Pacific whiting quota allocations (PFMC and NMFS, 2017)

Processing Facility	Initial Quota Allocation (%)
Bandon Pacific Inc.	0.738
Hallmark Fisheries	0.010
Jessie's Ilwaco Fish Co. Inc.	0.651
Ocean Beauty Seafoods LLC	0.873
Ocean Gold Seafoods Inc.	3.865
Pacific Choice Seafood Company	0.558
Pacific Coast Seafoods Company	3.793
Pacific Shrimp Company	2.853
Point Adams Packing Company	1.993
Trident Seafoods Corporation	4.666

2.3.2 Data Sources

We use several detailed data sources in this analysis. The main source of data is the National Marine Fisheries Service (NMFS) quota transactions database, which we use to compile a dataset of all processor-owned quota transfers from processors that received an initial allocation of harvesting quota to other entities in the fishery. All quota transactions must be completed through an online system operated by NMFS. The transferor of quota provides information including the amount of pounds transferred, species, date proposed, date acted on, total transfer value, the recipient of the quota, and the type of transfer. At the beginning of each calendar year, quota allocations are deposited into quota share (QS) accounts. In order for quota to be utilized in this fishery, quota must be transferred from QS accounts to vessel accounts (Holland and Norman, 2015; Holland, 2016; PFMC and NMFS, 2017). Processors that received an initial allocation of Pacific whiting quota have a quota share (QS) account and quota can be traced from this account to vessels throughout the season. Some processors also own vessel permits that received

allocations of harvesting quota, and hierarchical ownership information from NMFS West Coast Region Fisheries Permits Office allows for identification of these vessels. When vertical integration is present, it is common to observe quota transferred from processor QS accounts to vessels they own, and then subsequent transfers to independent vessels from that processor-owned vessel account. Therefore, it is impossible to determine whether the quota received by an independent vessel from a processor-owned vessel was initially processor-allocated quota (part of the 20%) or quota the processor-owned vessel was allocated or purchased. This study considers a transfer of quota from a processor to an independent vessel as any transfer from a processor QS account to that independent vessel as well as any transfer from a processor-owned vessel's account to that independent vessel. Evidence in the data as well as anecdotal evidence from conversations with industry participants indicate that distinctions between the two types of transfers are minor and not relevant for this analysis. For clarity and accuracy, the term "processor-owned quota" refers to all processor-allocated quota and all quota allocated to or acquired by a processor-owned vessel.

In order to explore the impact of processor-owned harvesting quota in the ex-vessel market, we pair our dataset of processor-owned quota transfers with fish ticket data from the Pacific Fisheries Information Network.²² Fish tickets provide information on all deliveries of Pacific whiting from vessels to processors, including date of landing, port of landing, pounds landed, and ex-vessel revenue. To develop parameter estimates for our simple model outlined in section 2.2, we use detailed processor-level cost-earnings data from the Economic Data Collection (EDC) Program at the Northwest Fisheries Science Center (NWFSC) (Guldin et al., 2017). The West Coast

²² For more details, see: <https://pacfin.psmfc.org/>

Groundfish Trawl Catch Share Program included a mandatory data collection of cost-earnings information from all program participants, including processors, in order to assess the program post-implementation. This study uses information on processors' variable costs, first-wholesale prices, and product recovery rates. Variable costs include expenses on labor, utilities, packing materials, freight, production supplies, taxes and licensing fees, and other expenses. These costs are collected for all operations at these multi-species processing facilities. In order to focus on Pacific whiting production, joint costs are disaggregated using methodology developed by the EDC Program, which is supported by the Scientific and Statistical Committee of the Pacific Fisheries Management Council (PFMC) (Guldin et al., 2017). EDC Program data is collected annually for each processor's fiscal year. The Pacific Coast Groundfish Fishery Social Study at the NWFSC (Russell et al., 2014) provides qualitative data from shoreside Pacific whiting processors. This voluntary survey is collected in person and survey responses are generally coupled with a transcript of the conversations with participants during survey completion. Quotes from these transcripts provide narratives to support and contextualize empirical findings.

In this study, we exclude active processors that did not receive quota as part of the 20% allocation to the processing sector, as these processors may have engaged in other informal arrangements with vessels that we cannot capture in this analysis. We also drop interactions between vertically-integrated processors and vessels owned by that processor. Using a processor-owned vessel to harvest processor-allocated quota is different from informally contracting with independent vessels. We focus on the latter in this study given the amount of quota transferred from processors (including vertically-integrated processors) to independent delivering vessels, and leave examination of quota utilization via vertical integration to future work.

2.3.3 Leasing in Quota Market²³

Using the NMFS quota transactions database, we can examine the complete set of quota transactions from processors that were allocated quota to independent vessels in the fishery for evidence of leasing in the quota market, indicated by a positive transfer value at the time of the quota transfer. Between 2011-2017, there were 455 quota transactions involving processors transferring quota to independent vessels. Only 5% of these transfers had a non-zero transfer value recorded for the transaction, which accounted for 8% of total processor-owned quota pounds transferred over this period. It is possible that the price was not known at the time of the transfer or that the price was not recorded, but the transferor also identifies a transfer type from a drop-down list and only 7% of overall transfers were designated as either “cash sale” or “cash and barter.” This provides some evidence that processors are not trading quota for a lease fee in arm’s-length transactions in the quota market. In addition, over 95% of processor-owned quota transfers were to vessels that delivered Pacific whiting to that processor during the season, suggesting that processors may be using quota as part of negotiations with delivering vessels in the ex-vessel market.

Narratives from industry support the assertion that contracting quota may be preferable to the leasing strategy in this fishery. In transcripts from the Pacific Coast Groundfish Fishery Social Study, two processors describe a strategy of offering quota to delivering vessels as a percentage of landings in order to secure market share (PFMC and NMFS, 2017):

“As a plant, I just have the quota and now I use it to spread amongst the boats I have as a carrot. To make me the mark of choice.” (*Pacific whiting Processor*)

²³ An earlier version of the analysis in subsection 2.3.3 can be found in PFMC and NMFS (2017).

“Well, there was an agreement uh amongst the processors...for Pacific whiting. In order for the processors to have access to the 20% share that we got, we agreed that we would make the fishermen whole. And so that means that ...if a fisherman makes a delivery, and the fisherman has 80%... I’ve got to make up 20% points. So that’s 25% of his delivery pounds to make him 100%.” (*Pacific whiting Processor*)

Economic theory suggests that processor-owned quota would be less valuable in years when the TAC does not bind. We observe lower utilization of processor-owned quota on average in 2014-2017 relative to 2011-2013. In addition, an average of 82% of processor-vessel relationships involved a quota transfer in binding TAC years (accounting for 98% of delivered pounds on average) compared to 51% of relationships during non-binding TAC years (accounting for 75% of delivered pounds on average). As we estimate the impacts of processor-owned quota on ex-vessel prices and quantity supplied in the next few subsections, we consider binding and non-binding TAC years separately to assess the potential differences.

2.3.4 Indirect Pricing of Quota in Ex-vessel Market

As the majority of processor-owned quota transfers are to delivering vessels, processors could be pricing quota indirectly in the ex-vessel market by offering a discounted ex-vessel price (less some contracting premium per pound of quota transferred to the vessel from that processor). We assume the per-pound contracting premium is less than or equal to the market quota price or the vessel would opt to lease quota in the quota market over contracting. Transcripts from the Pacific Coast Groundfish Fishery Social Study suggest that pricing of quota may not be occurring in this fishery (PFMC and NMFS, 2017):

“I am going to let you catch it and I am going to pay fair market value for it. I am paying you to catch my fish and I will do that” (*Pacific whiting Processor*)

“We’re not leasing it out, we have to give it to them... You can’t even charge a lease fee for it. If we want their 5 million pounds of whiting, we have to give them 1.5 million of our own.” (*Pacific whiting Processor*)

We can use fish ticket data to explore this question empirically. If indirect pricing of quota is occurring, the observed ex-vessel revenue that vessel i receives from processor j for deliveries in time period t ($rev_{i,j,t}$) can be decomposed into an ex-vessel price (p_t^x) paid on all whiting delivered ($Q_{i,j,t}$) minus a contracting premium (p_t^c) the vessel pays on all processor-owned quota pounds transferred from that processor ($Q_{i,j,t}^P$), such that:

$$rev_{i,j,t} = p_t^x Q_{i,j,t} - p_t^c Q_{i,j,t}^P$$

Pre-IFQ data from 2005-2010 is combined with IFQ data from 2011-2017 to produce an unbalanced panel of processor-vessel pairs in each time period t . In IFQ years, we must match quota transfers to landings or groups of landings for each processor-vessel pair in time period t , which can be challenging. The timing, volume, and number of quota transfers throughout a season varies widely across processors, processor-vessel pairs, and seasons, as informal contracting can take on a variety of forms within the context of long-term processor-vessel relationships. Given this complexity, our preferred matching method is at the season level, matching aggregated seasonal processor-owned quota transfers to that vessel with seasonal landings from that vessel for

each processor-vessel pair. While this method loses data granularity in cases where multiple quota transfers occur between a processor-vessel pair in a season (an average of three transfers occur between processor-vessel pairs within a season), this seasonal matching method produces a consistent time period t across processor-vessel pairs and is arguably the least likely to produce mismatches. As a robustness check, we develop an intra-seasonal method leveraging some patterns observed in the data to match quota transfers to landings within seasons. This method utilizes a backward-looking approach where the first quota transfer of a season for a processor-vessel pair is matched with landings from the beginning of the season to the date of the transfer, the second quota transfer is matched with landings since the first quota transfer up to the date of the second quota transfer, and so on (see Figure A.1 in Appendix A). In cases where landings occur after the last quota transfer, those landings are matched with that quota transfer. This method allows t to vary for each observation, where observations in pre-IFQ years are individual landings and observations in IFQ years are groups of landings for processor-vessel pairs (or entire seasons for cases where one quota transfer occurred). A disadvantage to this method is that it assumes that processors do not have forward-looking arrangements with delivering vessels, which anecdotal evidence indicates is not always the case.

Utilizing these two matching methods, we estimate the ex-vessel price and the per-pound contracting premium with the following regression:

$$rev_{i,j,t} = \beta_1(year * Q_{i,j,t}) + \beta_2(bindingTAC * Q_{i,j,t}^P) + \varepsilon_{i,j,t} \quad (1)$$

where *year* is a year indicator variable and *bindingTAC* is a dummy variable that is 1 in years when the TAC binds under IFQs (2011-2013) and 0 in all remaining years. β_2 is a vector of the estimated average per-pound contracting premium in binding TAC years and non-binding TAC years under IFQs. A negative value on the estimated contracting premium illustrates a discount to the ex-vessel price. β_1 is a vector of the estimated annual average ex-vessel price per pound. Summary statistics can be found in Tables A.1 and A.2 in Appendix A.

We also estimate a separate per-pound contracting premium for each year in regression 2 below:

$$rev_{i,j,t} = \beta_1(year * Q_{i,j,t}) + \beta_2(year * Q_{i,j,t}^P) + \varepsilon_{i,j,t} \quad (2)$$

Table 2.2 presents the results for regression 1 (specifications 1 and 3) and regression 2 (specifications 2 and 4). Both the seasonal and intra-seasonal models find some evidence of indirect quota pricing via a contracting premium in years when the TAC was binding. The premium is estimated to be between 1.12 and 1.45 cents per pound of processor-owned quota transferred. This is less than the market quota price in 2011-2013, which ranges from two to five cents per pound (see Table 2.3 below). If we estimate the average contracting premium in all years, the seasonal model finds only significant values in 2011, while the intra-seasonal model finds some evidence of indirect quota pricing in each year of binding TAC. For all specifications, values of p^c in non-binding TAC years were not statistically different from zero.

Table 2.2: Ex-vessel price regressions (2005-2017)

Ex-vessel Revenue (cents)	Seasonal		Intra-seasonal	
	(1)	(2)	(3)	(4)
Estimated Contracting Premium, $-p^c$ (cents)				
Binding TAC years (2011-2013)	-1.45**	---	-1.12***	---
Non-binding TAC years (2014-2017)	0.2227	---	0.1101	---
2011	---	-1.29**	---	-1.17**
2012	---	-2.97	---	-1.67**
2013	---	-0.8248	---	-0.6900*
2014	---	0.8599	---	-0.1089
2015	---	-0.1664	---	0.0029
2016	---	2.49	---	2.30
2017	---	-0.1953	---	-0.2044
Estimated Ex-vessel Price, p^x (cents)				
2005	6.34***	6.34***	6.37***	6.36***
2006	7.29***	7.29***	7.42***	7.42***
2007	8.86***	8.86***	8.95***	8.95***
2008	13.05***	13.05***	13.10***	13.10***
2009	7.47***	7.47***	7.50***	7.50***
2010	8.47***	8.47***	8.78***	8.78***
2011	12.92***	12.86***	13.85***	13.86***
2012	15.66***	16.15***	17.00***	17.12***
2013	13.96***	13.77***	14.20***	14.08***
2014	11.55***	11.38***	11.91***	11.96***
2015	7.99***	8.07***	7.97***	8.00***
2016	7.05***	6.63***	7.62***	7.13***
2017	7.84***	7.91***	7.55***	7.62***
R-squared	0.9939	0.9940	0.9929	0.9930
N	375	375	4,350	4,350

***, **, * indicates significance at the 1%, 5%, and 10% levels respectively.

2.3.5 Conditions for Contracting

In the previous two subsections, we found some evidence that processors are using processor-allocated quota to informally contract with delivering vessels in the ex-vessel market. The model outlined in section 2.2 illustrates that a processor will prefer to contract a unit of processor-owned quota over leasing it in the quota market if the expected increase in delivered pounds is greater than the ratio of the market quota price and marginal profit from processing a pound of fish. We can further explore the existence of informal contracting of processor-owned quota in the shoreside Pacific whiting fishery by comparing the market quota price and the marginal processing profit using processor-level cost-earnings data from the EDC Program.

We use a weighted average of closing prices from quota transactions made via the Jefferson State Trading Company online auction as an estimate for the market quota price in each year.²⁴ As we would expect, market quota prices were lower in 2014-2017 when the TAC was underutilized relative to 2011-2013 when market quota prices were an average of 3 cents per pound (Table 2.3). To generate an estimate of a representative processor's marginal profit from processing whiting, we approximate the marginal profit for each whiting processor ($\alpha_i p_i^w - p_i^x - c_i$) by calculating the operating net revenue of each firm, where

$$\alpha_i p_i^w = \frac{\text{whiting production value of facility } i}{\text{pounds of raw whiting purchased by facility } i}$$

$$p_i^x = \frac{\text{cost of raw whiting of facility } i}{\text{pounds of raw whiting purchased by facility } i}$$

²⁴ No Pacific whiting quota was transferred through Jefferson State Trading Company in 2015, and so we use single-species cash trades of whiting in the NMFS quota transactions database for 2015, following Holland (2016).

$$c_i = \frac{\text{whiting variable costs of facility } i}{\text{pounds of raw whiting purchased by facility } i}$$

We assume constant marginal costs for processors in the shoreside whiting sector, which is a reasonable simplifying assumption given that season lengthening did occur under IFQs (Guldin and Anderson, 2018; Errend et al., 2019; Guldin et al., 2019); thus, overcapitalization was probable in the processing sector during the first few years of the IFQ program transitioning from a race-to-fish. Only non-fish variable costs are included in marginal cost.

Table 2.3: Processor average operating net revenue from processing whiting (and components), market quota price, and contracting Δq threshold $\left(\frac{p^q}{\alpha p^w - p^x - c}\right)$.

Year	αp^w	p^x	c	$\alpha p^w - p^x - c$	p^q	$\frac{p^q}{\alpha p^w - p^x - c}$
2011	0.34	0.11	0.14	0.09	0.02	0.22
2012	0.41	0.14	0.16	0.11	0.05	0.45
2013	0.32	0.13	0.13	0.06	0.03	0.50
2014	0.33	0.12	0.12	0.09	0.03	0.33
2015	0.33	0.08	0.20	0.05	0.01	0.20
2016	0.26	0.08	0.16	0.02	0.01	0.50
2017	0.29	0.08	0.16	0.05	0.01	0.20

Summary statistics in Table 2.3 show that the average operating net revenue of Pacific whiting processors from 2011 to 2017 is at least twice as high as the observed market quota prices. The Δq threshold to induce contracting ranges from 0.20 to 0.50, which indicates that processors would prefer to contract a pound of quota even if only a fraction of that pound is delivered back to them.

In the next subsection, we estimate Δq in the shoreside Pacific whiting fishery to explore to what extent contracting processor-owned quota can increase deliveries.

2.3.6 Estimating Vessel Supply

To estimate Δq in this fishery, we analyze determinants of the supply of raw fish to processing facilities. We model vessel supply at the landings level using a conditional logistic framework (McFadden, 1973) to examine vessels' decisions throughout the season of where to land their catch. In the shoreside Pacific whiting fishery, the number of landings a processor receives in a season is directly proportional to the quantity supplied to that processor²⁵ and the conditional logistic framework offers several advantages over modeling a traditional supply function. First, it considers the set of alternatives (processors) a vessel can choose for each landing decision, and allows for estimation of the probability of landing with processors that were not chosen in the observational data. Second, it allows inclusion of alternative-specific covariates as determinants of the supply decision, primarily ex-vessel price and measures of existing vessel-processor relationships in the fishery. If quota is valuable to vessels, the amount of processor-owned quota offered by each processor will also influence this decision. Our discussions with industry participants indicate that processors offer quota to delivering vessels by matching a portion of their landings with quota; therefore, we consider how this quota match rate influences vessel supply.

For each landing ($Y_{i,t}$), vessel i chooses which processor to deliver to. The vessel's decision is represented by an indicator variable, $y_{i,j,t}$, such that $y_{i,j,t} = \mathbf{1}(Y_{i,t} = j)$. Using an additive random

²⁵ Using a processor-season panel dataset, a simple OLS regression of share of pounds landed on share of landings yields a coefficient of 1.07.

utility model, vessel i chooses to deliver a landing to processor j on day t if and only if utility from delivering to processor j is greater than or equal to utility from delivering elsewhere (i.e., $u_{i,j,t} \geq u_{i,-j,t}$), where $u_{i,j,t}$ is specified as the following:

$$u_{i,j,t} = \mathbf{x}'_{i,j,t}\boldsymbol{\beta} + \epsilon_{i,j,t}$$

$\mathbf{x}_{i,j,t}$ is a vector of alternative-specific covariates, and the probability that vessel i chooses processor j on day t is

$$\text{Prob}\{y_{i,j,t} | \mathbf{x}_{i,1,t}, \mathbf{x}_{i,2,t}, \dots, \mathbf{x}_{i,J,t}\} = \frac{\exp\{\mathbf{x}'_{i,j,t}\boldsymbol{\beta}\}}{\sum_{j=1}^J \exp\{\mathbf{x}'_{i,j,t}\boldsymbol{\beta}\}}$$

We empirically model vessels' unobserved utility ($u_{i,j,t}^*$) with the following

$$u_{i,j,t}^* = \alpha_j + \beta_1 \theta_{i,j,t} + \beta_2 \log(p_{i,j,t}^x) + \beta_3 y_{i,j,t-1} + \beta_4 s_{i,j,t} + \epsilon_{i,j,t}$$

The dependent variable, $y_{i,j,t}$, is 1 if vessel i lands with processor j and 0 otherwise, where only one alternative is chosen for each landing.²⁶ Our covariate of interest is the quota match rate offered by processor j to vessel i at time t , denoted by $\theta_{i,j,t}$. We hypothesize that quota match rate is an important determinant of vessel supply in all years, and has a greater impact in seasons where the TAC binds. We include several additional alternative-specific covariates to control for other

²⁶ For the majority of landings, all processors are alternatives from which the vessel can choose; however, Pacific whiting processors are multi-species facilities and, therefore, may not have whiting operations all days of the whiting season. Processors are considered available to receive whiting landings at any time between their first and last observed purchase of whiting. In addition, one processor exited the fishery and did not operate in 2017.

important factors in the vessels' delivery decision, including the log of the ex-vessel price offered by processor j to vessel i at time t , denoted by $\log(p_{i,j,t}^x)$, which we expect to have a positive and significant impact on vessels' delivery decisions. Given that vessels make repeated decisions within and across seasons, it is likely that past behavior and existing relationships are also important drivers of supply in this fishery. Vessels may prefer to land with a processor they are already associated with, leading to choice persistence. In the literature on dynamic decision-making, there are two main sources of choice persistence (Heckman, 1981). One is state dependence, where similar individuals make different decisions based on experience. The second source is heterogeneity that persist over time, where unobserved tastes influence individuals' preferences for certain alternatives. An example of state dependence in this context would be if a vessel delivers to a processor and establishes an informal contract to deliver the next several landings with that processor as well. In an effort to control for state dependence and potential linkages between sequential decisions, we include a dummy variable that indicates whether vessel i 's previous landing was with processor j ($y_{i,j,t-1}$). As a proxy control for heterogeneity, we include a variable to measure the strength of existing relationships in the fishery: the share of vessel i 's total landed pounds of whiting that were delivered to processor j the previous season ($s_{i,j,t}$).

Generation of $y_{i,j,t-1}$ and $s_{i,j,t}$ are straightforward using fish ticket data. For our variable of interest, we use our preferred seasonal method of quota matching outlined in subsection 2.3.4 to generate the observed annual quota match rates for each processor-vessel pair, where the quota match rate is calculated as total seasonal processor-owned quota pounds transferred to the vessel divided by the total seasonal pounds delivered by that vessel. The quota match rate will vary across processor-vessel pairs and seasons but we assume that vessels expect to receive the same quota

match rate for each landing delivered to that processor throughout each season. If a processor-vessel pair has no interactions during a season, we must impute the quota match rate a vessel would have expected to receive had they landed with that processor. We use an average of the observed match rates offered by that processor to other vessels that season as an approximation for what vessels would expect to receive from a given processor.²⁷ Fish ticket data yields the landing-specific ex-vessel price for all observed landings. Ex-vessel prices for alternatives not chosen are imputed using a moving average of observed ex-vessel prices offered by that processor with a seven-day lag. If no prices are observed in the seven days prior to the potential landing, we utilize a 14-day lag. If no prices are observed in the 14 days prior, we use a monthly lag and so on. Summary statistics of all variables used to estimate vessel supply are in Table A.3 in Appendix A.

Table 2.4 illustrates the results from the conditional logistic model of vessels' delivery decisions. Specification 1 provides a baseline estimation of the model without controlling for the quota match rate. We build upon this baseline estimation in two different ways. Specification 2 estimates the impact of quota match rate for all years and specification 3 estimates the impact of the quota match rate separately for years when the TAC was and was not binding. In all three specifications, coefficients on the state dependence and heterogeneity controls are highly significant, suggesting persistence in vessels' delivery decisions. Vessels' previous landing decision has a large positive impact on current decision and vessels are more likely to land with processors they had a strong relationship with the previous season (as measured by share of landings during prior season). Contrary to expectations, the sign on the ex-vessel price coefficient is negative; however, it is not

²⁷ We exclude the few quota match rates over 100% from these calculations, as they are highly irregular and not indicative of what the average vessels is likely to receive from a processor.

statistically significant, indicating that ex-vessel price offerings may not be as important as other factors in vessels' delivery decisions.

Table 2.4: Landings-level conditional logistic model (2011-2017)

	(1)	(2)	(3)
Log of ex-vessel price (cents)	-0.6302 (.4482)	-0.6431 (.4537)	-0.5031 (.4643)
Quota match rate (percent)	---	0.0057* (.0034)	---
Quota match rate in binding TAC years (percent)	---	---	0.0103*** (.0038)
Quota match rate in non-binding TAC years (percent)	---	---	-0.0077 (.0072)
Last landing to processor (dummy)	3.916*** (.1043)	3.915*** (.1046)	3.918*** (.1050)
Share of landed pounds to processor last season (percent)	0.0198*** (.0013)	0.0196*** (.0013)	0.0201*** (.0014)
N (cases)	3,815		
Pseudo R-squared	0.8612	0.8615	0.8620

***, **, * indicates significance at the 1%, 5%, and 10% levels respectively. Standard errors in parentheses. Coefficients illustrate the impact of a one-unit change in each covariate on the log-odds of landing.

The coefficient on quota match rate (Table 2.4, specification 2) is positive and weakly significant, providing some evidence that processor-owned quota can be an important tool to attract deliveries as vessels are more likely to land with a processor that offered more quota. When we examine the impact of quota match on supply separately for binding and non-binding TAC years (Table 2.4, specification 3), we find processor-owned quota offerings are only useful for securing landings in years when the TAC was binding. As with the ex-vessel price analysis in subsection 2.3.4, we find no significant impact of processor-owned quota transfers in non-binding TAC years, which is interesting given that processors are still distributing quota to some extent in these years. A

likelihood-ratio test comparing specification 3 to specification 1 rejects the null hypothesis that specification 1 captures the same information as specification 3 at the 5% level, revealing the importance of processor-owned quota in the vessel supply function.

The coefficient in specification 3 indicates that a 1% increase in the quota match rate from a processor increases the expected probability of landing with that processor by approximately 1.03% on average during binding TAC years. This implies $\Delta q = 1.03$, i.e., contracting one additional unit of processor-owned quota increased delivered pounds by 1.03 on average. This estimated Δq is larger than the theoretical threshold to induce processors to contract over leasing in this fishery outlined in Table 2.3; however, it is interesting to note that the empirical results indicate a one-for-one trade of quota pounds for delivered pounds, rather than processor-owned quota holdings allowing processors to attract additional deliveries beyond their quota holdings. Conversations with industry members imply that quota match rate offerings by processors are likely related to other factors in the model, with processors offering higher quota match rates to vessels they have stronger existing relationships with. These potential correlations make imputing unobserved quota match rates challenging, and make identifying the magnitude of the impact of processor-owned quota on quantity landed difficult, as it is possible that some of the impact is being absorbed into those effects.

We include two robustness checks in Appendix B, which provide support that quota match rate offerings by processors are an important determinant of vessel supply in this fishery under IFQs. First, we estimate vessel supply using a mixed logit model, or random parameters logit model. This allows for estimation of coefficients that vary across choices, offering another way to capture

heterogeneity. We re-estimate specification 3 in Table 2.4 using a mixed logit model where $s_{i,j,t}$ is random (i.e., strength of existing relationships are more or less important for some vessels and/or more or less important for some landings). The results are very similar to those in Table 2.4, with an estimated $\Delta q = 1.05$ on average in binding TAC years (Table B.1). Second, we estimate a season-level conditional logistic model to consider the possibility that vessels' supply decisions are made at the season level, particularly given the large impact of the lagged dependent variable in the landings-level model. The results (Table B.3) are also generally consistent with a slightly higher magnitude effect of quota in binding TAC years (estimated $\Delta q = 1.24$).

2.4 Conclusion

In this study, we leverage several comprehensive data sources to analyze the shoreside Pacific whiting fishery under the first IFQ program to allocate harvesting quota to land-based processors. We are able to track all quota transferred from processors that received a portion of the 20% allocation to examine how processors utilized quota holdings under the first seven years of this IFQ program. We find processors engaged in informal contracting with delivering vessels, using processor-owned quota in ex-vessel market negotiations. We find some evidence that, by offering quota to match a portion of deliveries, processors were able to attract landings to their facility and charge vessels a contracting premium on quota pounds transferred. These impacts were only identified in seasons when the TAC was close to binding (utilization of TAC was greater than 95%) even though processors still utilize quota in non-binding TAC years. Reasons for this may be that quota transfers are valuable in non-binding TAC years earlier in the season (before realization that the TAC will not be fully utilized) or that quota transfers to certain vessels (perhaps those that hold less quota) still generate value, suggesting interesting extensions to this analysis.

The goal of allocating harvesting quota to the processing sector was to offer processors compensation for adverse impacts that may occur under IFQs, like shifts in bargaining power in the ex-vessel market. This analysis provides some evidence that this policy is meeting that objective as it indicates that processors are able to extract value from their quota allocation in years when quota is scarce. In order to better understand the implications of processor-allocated harvesting quota, more research is required on the one-pie split allocation, particularly regarding welfare outcomes of harvesters and processors and overall efficiency. In Guldin (Chapter 3), we develop a game theory model of a regionally-differentiated processing sector to further explore how using processor-owned quota to secure landings can impact general welfare outcomes in the ex-vessel market and speak more to the concerns that this policy could promote anticompetitive processor behavior. As the one-pie split allocation is a likely candidate for future IFQ programs, continuing to advance our understanding of the effects of such a policy is crucial.

Chapter 3

**PROCESSOR-ALLOCATED HARVESTING QUOTA IN THE EX-VESSEL MARKET:
A GAME THEORY APPROACH****Abstract**

Allocating harvesting quota to the processing sector in IFQ programs is a policy that has gained some traction in recent years, with implementation in the shoreside Pacific whiting fishery in 2011. This one-pie split allocation is a method to mitigate rent transfers from the processing sector to the harvesting sector that may arise during the transition to IFQs; although the extent to which these adverse impacts are likely to manifest in fisheries has been questioned and concerns have been expressed over potential effects of processor-allocated quota. Existing theoretical research on this policy considers quota holdings as a source of revenue for processors through leasing quota at the market quota price. However, in the Pacific whiting fishery, we observe processors using quota in ex-vessel market negotiations to secure landings. In this study, we build a novel modelling framework that incorporates processor-allocated harvesting quota in an ex-vessel market with a regionally-differentiated duopsony processing sector, focusing on processor use of quota holdings to attract deliveries and allowing for market frictions where vessels are heterogeneous in their costs of delivering to different processors. With this model, we explore how the one-pie split allocation can alter ex-vessel market outcomes in equilibrium when such frictions exist, providing some insights into the welfare costs and distributional consequences of this policy.

3.1 Introduction

Allocating harvesting quota to the processing sector in IFQ programs is a policy that has gained some traction in recent years as a method to mitigate potential rent transfers from the processing sector to the harvesting sector during the transition to IFQs (Matulich, Mittellhammer, and Reberte, 1996). Although the extent to which these adverse impacts to the processing sector are likely to manifest in fisheries has been questioned (Halvorsen, Khalil, Lawarree, 1999; Wilen, 2009; Fell and Haynie, 2010), fishery managers have considered processor-allocated harvesting quota in the design of recent IFQ programs. To date, this unprecedented policy has been implemented in one fishery: the shoreside Pacific whiting fishery in 2011, which allocated 20% of the harvesting quota allocation to the processing sector (PFMC and NMFS, 2010).

If rents are redistributed away from the processing sector under IFQs, processor-allocated harvesting quota can be leased in the quota market, providing some compensation to processors and reallocating rents from the harvesting sector back to the processing sector. Theoretical research on this policy has incorporated processor-allocated quota into models of the ex-vessel market in this way, where quota holdings are a source of revenue for processors through leasing quota at the market quota price (Matulich and Sever, 1999; Milon and Hamilton, 2002). However, another potential use of harvesting quota by processors is as an additional bargaining tool in the ex-vessel market to attract landings to their facility. In this way, a quota allocation “functions as a means of guaranteeing supply for processors” (PFMC and NMFS, 2010). We see evidence of this occurring in the shoreside Pacific whiting fishery, where processors distribute quota to delivering vessels to secure landings (Guldin, Chapter 2). Utilized in this way, processor-allocated quota has the potential to distort ex-vessel market outcomes and impact overall efficiency, particularly when

transaction costs are present in the ex-vessel market. Tying vessels to their historical processors can reduce competition between existing processors (Halvorsen, Khalil, Lawarree, 1999) and create barriers to entry reducing the potential for long-term competition (Wilens, 2008; Wilens, 2009). In this study, we build a novel modelling framework that incorporates processor-allocated harvesting quota into the ex-vessel market, focusing on processor use of quota holdings to attract deliveries. Following Milon and Hamilton (2002), we characterize the processing sector as a regionally-differentiated duopsony. With our model, we allow for market frictions where vessels are heterogeneous in their costs of delivering to different processors and explore how processor-allocated harvesting quota can lead to ex-vessel market distortions when such frictions exist, providing some insights into the welfare costs and distributional consequences of this policy.

Fisheries management programs often include competing objectives involving tradeoffs between efficiency and other goals, like conservation and community preservation that may require market distortions. If processors use quota allocations to secure landings, an argument in favor of the one-pie split allocation is that it can promote community stability, mitigating regional shifts in participation that may arise under harvester-only IFQs (PFMC and NMFS, 2010). If quota is tradeable, IFQs foster economic efficiency as quota consolidates into the hands of those with the highest value, which often leads to exit in the harvesting sector. Loss of fishing activity in certain ports could reduce processing activity and other infrastructure that support harvesting and processing (GAO, 2004; PFMC and NMFS, 2010), adversely affecting downstream sectors like fish processors and fishing communities, particularly those highly dependent on the rationalized fishery (Carothers, 2008; Carothers et al., 2010). As more IFQ programs have been implemented and assessed over the years, understanding of their economic impacts has grown (McCay, 2004;

Olson, 2011), and program design has evolved to include the often competing goals of ecological, economic, and community sustainability (Anderson et al., 2018a). The 1996 reauthorization of the Magnuson-Stevens Fisheries Conservation and Management Act added National Standard 8, which states that fisheries management measures should, in accordance with conservation goals, “take into account the importance of fishery resources to fishing communities... in order to (a) provide for the sustained participation of such communities, and (b) to the extent practicable, minimize adverse economic impacts on such communities.”²⁸ Measures like accumulation limits, which cap the amount of quota an entity can control or own, and community-owned harvesting quota have been implemented in programs to lessen distributional effects of IFQs. There is some evidence that programs that allow communities to hold quota, like the Western Alaska Community Development Quota (CDQ) Program, have been successful at preserving regional participation in fisheries (Anderson et al., 2018b) and creating wealth and employment in communities (Haynie, 2014). As processors are relatively immobile, processor-allocated harvesting quota may also promote stability of coastal fishing communities by protecting processing investments in the fishery. Continued processing activity can be beneficial to communities if processing facilities are a source of employment for community members and if they distribute quota to local vessels. It can also help ensure continued activity of other fishery-related industries that might also be present in the community. We utilize our model to consider a policy where processors are allocated quota according to their pre-IFQ market share. Our model illustrates that processor-allocated quota assists in stabilizing market share over a transition to IFQs, but getting the initial quota allocations right is important, which may be challenging in practice.

²⁸ <https://www.fisheries.noaa.gov/national/laws-and-policies/national-standard-guidelines>

The layout of this paper is as follows. In section 3.2, we introduce the model. We begin by outlining the ex-vessel market prior to IFQ implementation. Then we build on this to consider the fishery under two different IFQ systems: a harvester-only IFQ system and one with processor-allocated harvesting quota. In section 3.3, we discuss comparative statics of the IFQ system with processor-allocated quota relative to the harvester-only system to explore how the one-pie split allocation can affect equilibrium strategies and outcomes under IFQs. In section 3.4, we consider a transition to IFQs, comparing the pre-IFQ equilibrium to that obtained under both IFQ systems to consider processor-allocated quota as a tool for community stability following regional shifts in harvester participation under IFQs. In section 3.5, we conclude and discuss extensions.

3.2 Model

3.2.1 Pre-IFQs

We model the ex-vessel market in a TAC-regulated fishery as a fixed-location Hotelling model (Hotelling, 1929) where regionally-differentiated processors compete in a Bertrand pricing game. Two land-based fish processors operate at fixed locations on opposite ends of a line segment $[0, 1]$, and choose ex-vessel prices (p_1, p_2) to maximize profit in a one-shot game. Processors incur a constant marginal cost of processing, which we assume to be zero. For the purposes of this study, we assume that the one-shot game captures a season in this fishery; however, that need not be the case. In another context, it may be more useful to consider this game occurring on a daily or weekly basis, repeated throughout the season.

Vessels are distributed uniformly over the $[0, 1]$ interval (Figure 3.1). We assume harvesting is costless and the market is covered, so each vessel harvests fish and delivers to one of the

processors. The total number of vessels is normalized to 1 and the mass of vessels is equal to the TAC (Figure 3.1), so the amount of fish each vessel catches is numerically equal to the TAC. Vessels incur a travel cost per unit of distance to deliver raw fish to each processor. In the standard Hotelling model, per-unit travel cost is the same to each firm. However, in this model, we allow for differences in the per-unit travel cost to each processor, such that vessels incur a travel cost, t_1 , per unit of distance to deliver raw fish to Processor 1 and incur a travel cost, t_2 , per unit of distance to deliver to Processor 2. This allows for heterogeneity in terms of processor location, where one processor might have a more advantageous location relative to the other.²⁹

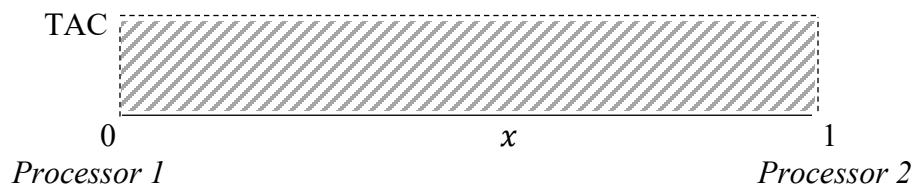


Figure 3.1: Space of pre-IFQ ex-vessel market Hotelling game.

While the Hotelling framework simplifies the harvesting sector to focus on processor interactions, the distance dimension allows inclusion of a continuum of heterogeneity in vessel-processor relationships. As our focus in this study is on regional impacts of IFQs, we consider distance as the physical distance between the vessel's haul or homeport and the two processors. However, the distance dimension in this model can more generally represent the strength of the relationship between the vessel and each processor, where the per-unit travel cost is a transaction cost. This feature of the model incorporates an important characteristic of real-world fisheries: that vessels have different relationships with processors that affect their costs of transacting with each. In

²⁹ This could also be accomplished by locating processors asymmetrically in space; however, that offers less flexibility for adjustments, which we employ under IFQs and discuss further in the next subsection.

reality, this one-shot game is repeated every season, or a number of times throughout a season, and long-standing relationships are costly to sever.

Vessels decide which processor to deliver to based on their distance from each processor and the ex-vessel prices offered. There is some vessel, located at \tilde{x} between the two processors that is indifferent between delivering to Processor 1 or Processor 2 (i.e., they receive the same profit from delivering to either processor). This vessel determines the total quantity of raw fish supplied to each processor, as all vessels located to the left of \tilde{x} deliver to Processor 1 and all vessels located to the right of \tilde{x} deliver to Processor 2 (Figure 3.2).

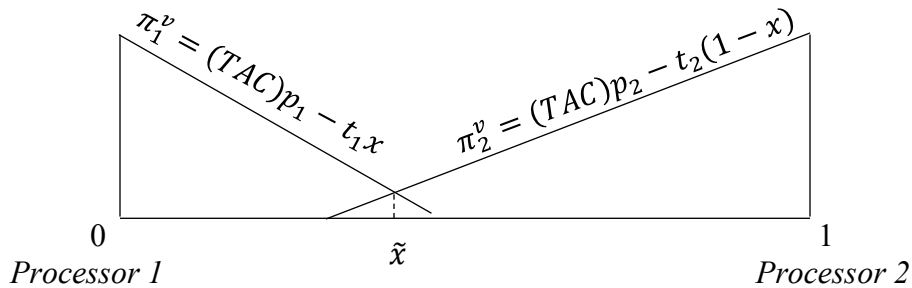


Figure 3.2: Example of indifferent vessel located at \tilde{x} that receives the same profit from delivering to Processor 1 as from delivering to Processor 2, where $t_1 > t_2$.

$$\pi_1^{vessel} = \pi_2^{vessel}$$

$$(TAC)p_1 - t_1\tilde{x} = (TAC)p_2 - t_2(1 - \tilde{x})$$

$$\tilde{x} = \frac{TAC(p_1 - p_2) + t_2}{t_1 + t_2}$$

$$1 - \tilde{x} = \frac{TAC(p_2 - p_1) + t_1}{t_1 + t_2}$$

Processor i 's decision is the following, where w is the industry-wide wholesale price:

$$\max_{\{p_i\}} \pi_i = (w - p_i)Q_i$$

Profit maximization yields the following best response function and equilibrium price and quantity for Processor i :

$$BR_i(p_j) = p_i = \frac{w + p_j}{2} - \frac{t_j}{2(TAC)}$$

$$p_i^* = w - \frac{t_i + 2t_j}{3(TAC)}$$

$$Q_i^* = \frac{TAC(t_i + 2t_j)}{3(t_i + t_j)}$$

Processors' best response functions are upward-sloping. As one processor increases ex-vessel price, the other processor's best response is to raise their ex-vessel price to compete for market share. If $t_1 = t_2$, processors are identical save their location in space. Thus, each processor continues to raise their ex-vessel price in response to an increase in the other processor's price until $p_1^* = p_2^* = w - t/TAC$ and the processors split the market ($Q_1^* = Q_2^* = 0.5 * TAC$). Processors do not have an incentive to capture a larger market share beyond this point as the ex-vessel price increase outweighs any increase in quantity supplied, yielding lower profit. If one processor has an advantage in terms of their location such that $t_i < t_j$, then asymmetry in the market allows Processor i to obtain a larger market share than Processor j while offering a lower ex-vessel price. The solution to this game represents the equilibrium in the fishery prior to the implementation of IFQs. Next, we extend this model to consider the ex-vessel market under an IFQ system.

3.2.2 IFQs

As this study focuses on processor-allocated harvesting quota as a potential tool for community stability, we assume that the transition to IFQs in this fishery has reduced harvesting capacity, which has shifted the regional distribution of harvesters making processors' fixed locations more or less advantageous. This could occur if entry and exit of harvesters due to IFQs is not regionally uniform. Rather than changing the shape of the distribution of harvesters in this model, we continue to employ the standard uniform distribution of the Hotelling framework and approximate the mechanics of these regional shifts by changing the per-unit travel costs to each processor. Therefore, we characterize the transition to IFQs in a fishery as a change in t_1 and/or t_2 from pre-IFQ levels. We consider two IFQ systems: one where only harvesters receive quota and one where some amount, θ , of the TAC is allocated to the processing sector (Figure 3.3).

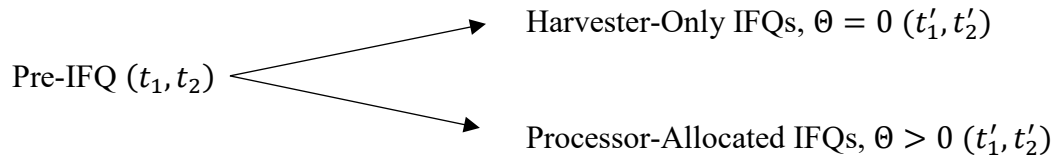


Figure 3.3: Characteristics of pre-IFQ fishery and the fishery under IFQs, where t_i is the per-unit travel cost to Processor i and θ is the amount of the TAC allocated to the processing sector.

3.2.2.1 Harvester-only IFQs

The ex-vessel market under a harvester-only IFQ system is characterized by the same model framework outlined in subsection 3.2.1 for the pre-IFQ market, but we assume t_1 and/or t_2 have changed due to IFQs. There are a number of other ways that IFQ implementation is likely to change fishery and ex-vessel market dynamics; however, for the purposes of this study, we simplify the transition to focus only on regional shifts in participation and discuss potential extensions in the

conclusion. We utilize this harvester-only IFQ model to compare market outcomes that arise when processors are allocated harvesting quota, which we outline in the next subsection, to the market outcomes that arise under the same fishery conditions where processors have no quota allocation.

3.2.2.2 Processor-allocated IFQs

Now we extend this model to consider the case where shoreside processors are allocated a portion of harvesting quota, denoted as Θ , and the only use of processor-allocated quota is to distribute it to delivering vessels (i.e., assume no selling or leasing of quota). The total processor quota allocation is divided amongst processors such that Processor i 's total harvesting quota allocation is $\alpha_i\Theta$. In the duopsony case, this reduces to an allocation of $\alpha\Theta$ to Processor 1 and an allocation of $(1 - \alpha)\Theta$ to Processor 2, where $\alpha \in [0, 1]$. Each vessel has one unit of harvesting quota that they can deliver to either Processor 1 or Processor 2. Processors match some portion of that with processor-allocated harvesting quota, offering a quota match rate, denoted as θ_i , such that each vessel delivers $(1 + \theta_i)$ units of fish to Processor i . The duration of the one-shot game represents a season in the fishery, and plays out in two stages. In the first stage, each processor chooses how much quota to distribute to delivering vessels (θ_1, θ_2) , constrained by their individual quota allocation. In the second stage, each processor chooses an ex-vessel price (p_1, p_2) , and each vessel delivers fish to one processor. The structure is akin to models in the industrial organization literature of firm advertising in markets for horizontally-differentiated goods (Grossman & Shapiro, 1984; Meurer & Stahl, 1994). Firms choose a level of advertising in the first stage and a price in the second stage, and advertising is used as a means to increase market share by attracting customers from other firms.

Vessels are uniformly distributed along the $[0, 1]$ interval (Figure 3.4), and, if the processors' quota constraints bind and they distribute all their quota, the mass of vessels is equal to the TAC ($\int_0^{\tilde{x}} (1 + \theta_1) dz + \int_{\tilde{x}}^1 (1 + \theta_2) dz = 1 + \Theta = TAC$). The supply of raw fish to each processor now depends on how much quota they own. There is some vessel located at \tilde{x} that is indifferent between delivering to Processor 1 or Processor 2, such that vessels located to the left of \tilde{x} will deliver to Processor 1 and vessels located to the right of \tilde{x} will deliver to Processor 2. Therefore, the total quantity of raw fish supplied to Processor 1 is $Q_1 = (1 + \theta_1)\tilde{x}$ and the quantity supplied to Processor 2 is $Q_2 = (1 + \theta_2)(1 - \tilde{x})$.

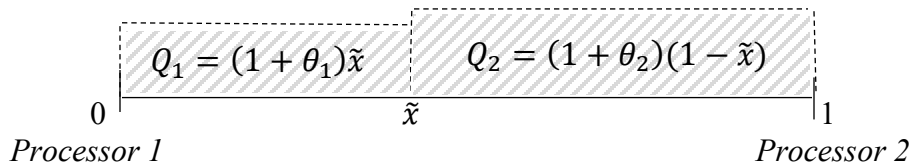


Figure 3.4: Example of space of ex-vessel market Hotelling game with processor-allocated quota where $\alpha < 0.5$.

In order to solve for the market equilibrium of this game, we need to employ backwards induction. First, we must solve for the optimal pricing strategies and quantity supplied in the second stage, which are functions of the first stage quota match rates (θ_1, θ_2) . Then we can utilize these functions to determine the optimal quota match rate strategies. Combining the optimal strategies for selecting quota match rates in the first stage and ex-vessel prices in the second stage yields the equilibrium of the two-stage game.

In the second stage, processors have chosen their quota match rates (θ_1, θ_2) and these are known to both processors and all vessels. Quantity supplied to each processor is determined by the location of the vessel that is indifferent between delivering to Processor 1 or Processor 2.

$$\pi_1^{vessel} = \pi_2^{vessel}$$

$$(1 + \theta_1)p_1 - t_1\tilde{x} = (1 + \theta_2)p_2 - t_2(1 - \tilde{x})$$

$$\tilde{x} = \frac{(1 + \theta_1)p_1 - (1 + \theta_2)p_2 + t_2}{t_1 + t_2}$$

$$1 - \tilde{x} = \frac{(1 + \theta_2)p_2 - (1 + \theta_1)p_1 + t_1}{t_1 + t_2}$$

Processor i 's second stage decision is the following:

$$\max_{\{p_i\}} \pi_i = (w - p_i)Q_i$$

Profit maximization yields the following best response function and equilibrium pricing strategy for Processor i :

$$BR_i(p_j) = p_i = \frac{(1 + \theta_i)w + (1 + \theta_j)p_j - t_j}{2(1 + \theta_i)}$$

$$p_i^* = \frac{w(3 + 2\theta_i + \theta_j) - t_i - 2t_j}{3(1 + \theta_i)}$$

These equilibrium pricing strategies yield the following equilibrium quantity supplied:

$$Q_i^* = (1 + \theta_i) \left(\frac{(\theta_i - \theta_j)w + t_i + 2t_j}{3(t_i + t_j)} \right)$$

In the first stage, processors choose quota match rate offerings, based on their knowledge of the supply response in the second stage, to maximize profit subject to their quota constraints. Non-negativity constraints are also included for all model parameters and choice variables, as well as a constraint to ensure the market is covered and all vessels deliver. Processor 1's first stage optimization is the following, utilizing pricing strategies and quantity supplied from the second stage:

$$\max_{\{\theta_1\}} \pi_1 = (w - p_1)Q_1$$

$$\text{subject to } \textit{Quota Constraint: } \theta_1 x \leq \alpha \Theta$$

$$\textit{Non-negativity Constraints: } w, t_1, t_2, \Theta > 0; 0 \leq \alpha \leq 1; \theta_1, \theta_2 \geq 0$$

$$\textit{Market Covered Constraint: } \pi^{vessel} \geq 0$$

$$\max_{\{\theta_1\}} \pi_1 = \left(w - \left[\frac{w(3+2\theta_1+\theta_2)-t_1-2t_2}{3(1+\theta_1)} \right] \right) (1 + \theta_1) \left(\frac{(\theta_1-\theta_2)w+2t_1+t_2}{3(t_1+t_2)} \right)$$

$$\text{subject to } \theta_1 \left(\frac{(\theta_1-\theta_2)w+2t_1+t_2}{3(t_1+t_2)} \right) \leq \alpha \Theta$$

Profit maximization yields the following piece-wise best response function for Processor 1:³⁰

$$BR(\theta_2) = \theta_1$$

$$= \begin{cases} \frac{\theta_2 w - t_1 - 2t_2 + \sqrt{12w\alpha\Theta(t_1+t_2) + \theta_2^2 w^2 - 2\theta_2 w(t_1+2t_2) + (t_1+2t_2)^2}}{2w} & \text{if } 0 < \alpha \leq 1 \\ 0 & \text{if } \alpha = 0 \end{cases}$$

³⁰ The best response functions shown here are simplified for relevance to this specific analysis given the parameter values explored in the next section. There are parameter values such that a processor's best response is to offer a zero match rate even if they do receive a quota allocation. If Processor i owns harvesting quota ($\alpha_i > 0$), then their best response is to generally offer a non-zero quota match rate in response to θ_j offered by Processor j . As θ_j increases beyond a certain point, Processor i 's best response is to continue to offer a non-zero quota match rate as long as the overall amount of processor-owned quota is above a certain threshold and Processor i 's portion of that processor-owned quota is above a certain threshold.

If $\alpha = 0$, then Processor 1 was not allocated any harvesting quota, in which case they cannot offer a quota match rate. Otherwise, profit maximization yields a best response function that is equal to the quota constraint, indicating that it is optimal for Processor 1 to set θ_1 such that their quota constraint binds and they distribute their entire harvesting quota allocation. This is an intuitive strategy for processors given they have constant returns to scale and there are no alternate uses of harvesting quota built into the model.

Processor 2's first stage optimization and resulting best response functions mirror Processor 1's:

$$\begin{aligned} \max_{\{\theta_2\}} \pi_2 &= \left(w - \left[\frac{w(3+2\theta_2+\theta_1)-2t_1-t_2}{3(1+\theta_2)} \right] \right) (1 + \theta_2) \left(\frac{(\theta_2-\theta_1)w+t_1+2t_2}{3(t_1+t_2)} \right) \\ &\text{subject to } \theta_2 \left(\left(\frac{(\theta_2-\theta_1)w+t_1+2t_2}{3(t_1+t_2)} \right) \right) \leq (1 - \alpha)\Theta \end{aligned}$$

Profit maximization yields the following piece-wise best response function for Processor 2:

$$\begin{aligned} BR(\theta_1) &= \theta_2 \\ &= \begin{cases} \frac{\theta_1 w - t_2 - 2t_1 + \sqrt{12w(t_1 + t_2)(1 - \alpha)\Theta + \theta_1^2 w^2 - 2\theta_1 w(2t_1 + t_2) + (2t_1 + t_2)^2}}{2w} & \text{if } 0 \leq \alpha < 1 \\ 0 & \text{if } \alpha = 1 \end{cases} \end{aligned}$$

Equating these two best response functions yields expressions for the equilibrium quota match rates; however, the complexity of the functional form prevents insightful explorations algebraically. Therefore, we parameterize the model in the next section to analyze the equilibrium of this two-stage game and comparative statics.

3.3 Numerical Analysis of Equilibrium and Comparative Statics

3.3.1 Homogenous Per-Unit Travel Costs

First, we explore the case of homogenous per-unit travel costs to each processor such that $t_1 = t_2$, and discuss when $t_1 \neq t_2$ in the next subsection. To characterize the equilibrium, we assume $\alpha = 0.5$, such that the overall processor quota allocation is split equally between the two processors. According to their best response functions, each processor chooses the quota match rate offering that allows them to distribute their entire quota allocation to delivering vessels given the quota match rate offered by the other processor. Equilibrium quota match rates are illustrated by the intersection of the two best response functions (Figure 3.5). Any choice of quota match rate by Processor 1 to the left of equilibrium results in Processor 2 using less than their entire quota allocation, which is suboptimal. Processor 2's best response is to offer a higher quota match rate that binds their quota constraint, which would in turn lead Processor 1 to choose a higher quota match rate, and so on, until equilibrium is reached. Any choice of quota match rate by Processor 1 to the right of equilibrium results in Processor 2 attempting to use more quota than they were allocated. Unable to do this, Processor 2's best response is to offer a lower quota match rate that binds their quota constraint, which would in turn lead Processor 1 to choose a lower quota match rate, and so on, until equilibrium is reached.

The first-stage equilibrium quota match rates combined with the second-stage pricing strategies yield best response functions for choice of ex-vessel price by each processor, the intersection of which indicate equilibrium ex-vessel prices (Figure 3.5). When $t_1 = t_2$ and $\alpha = 0.5$, processors choose to offer identical quota match rates ($\theta_1^* = \theta_2^*$) and ex-vessel prices ($p_1^* = p_2^*$) in equilibrium (Figure 3.5), and each processor purchases half of the TAC (Figure 3.6).

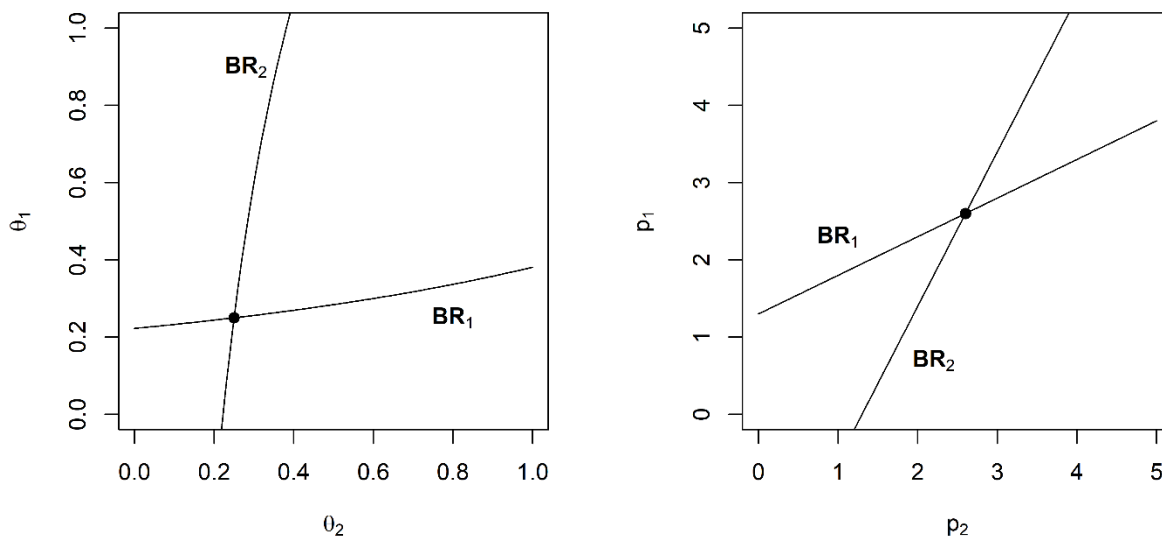


Figure 3.5: Processor best response functions for quota match rate (left) and ex-vessel price (right) given $\alpha = 0.5, \Theta = 0.25, w = 5, t_1 = t_2 = 3$.³¹

If we consider a fishery under the same market conditions but where processors were not allocated quota, we find that the equilibrium ex-vessel prices and market outcomes are identical to those in the processor-allocated quota market when $\alpha = 0.5$ in the case of homogenous travel costs (Figure 3.6). We illustrate in the theorem below that this will always be the case when the distribution of quota between the two processors reflects the market share that would arise in the absence of processor-allocated quota (i.e., $\alpha = x^H$, where H denotes the harvester-only IFQ equilibrium).

³¹ We consider the case where processors are allocated 20% of the overall TAC ($\Theta = 0.25$) to match the shoreside Pacific whiting fishery, which is the only fishery to-date to allocate harvesting quota to processors.

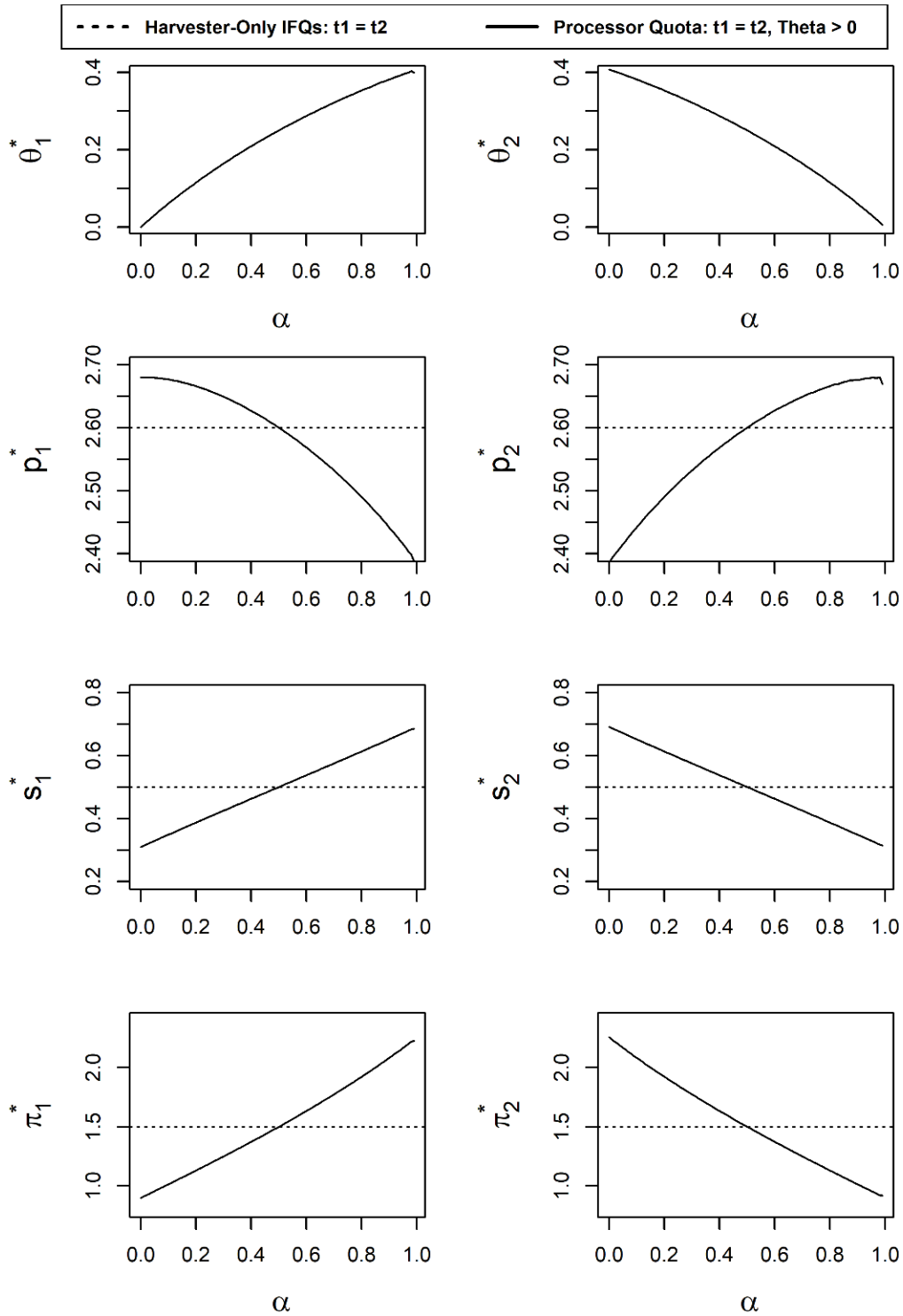


Figure 3.6: Processors' equilibrium quota match rates (θ_1^*, θ_2^*), prices (p_1^*, p_2^*), market shares (s_1^*, s_2^*), and profits (π_1^*, π_2^*) for $\alpha \in [0, 1]$, when $\Theta = 0.25, w = 5, t_1 = t_2 = 3$. The dotted lines illustrate the equilibrium under harvester-only IFQs.

Theorem: *When $\alpha = x^H$, the equilibrium price and market outcomes are equal to those that arise in equilibrium in a market under the same fishery conditions where there is no processor-allocated quota (i.e., a harvester-only IFQ system).*

Under the harvester-only IFQ system, the following is true:

$$x^H = \frac{t_1 + 2t_2}{3(t_1 + t_2)}$$

The equilibrium price and market share for Processor i are characterized by the following:

$$p_i^H = w - \frac{t_i + 2t_j}{3(TAC)}; \quad s_i^H = \frac{t_i + 2t_j}{3(t_i + t_j)}$$

In a market with processor-allocated quota, the equilibrium price and market share for Processor i are characterized by the following when vessels incur different per-unit travel costs to each processor, where $1 + \Theta = TAC$:

$$p_i^* = \frac{w(3 + 2\theta_i + \theta_j) - t_i - 2t_j}{3(1 + \theta_i)}; \quad s_i^* = \frac{Q_i^*}{TAC} = \frac{(1 + \theta_i) \left(\frac{(\theta_i - \theta_j)w + t_i + 2t_j}{3(t_i + t_j)} \right)}{1 + \Theta}$$

The equilibrium quota match rates are determined by the intersection of the two processors' best response functions.

$$BR(\theta_2) = \theta_1 = \frac{\theta_2 w - t_1 - 2t_2 + \sqrt{12w(t_1 + t_2)\alpha\Theta + \theta_2^2 w^2 - 2\theta_2 w(t_1 + 2t_2) + (t_1 + 2t_2)^2}}{2w}$$

$$BR(\theta_1) = \theta_2$$

$$= \frac{\theta_1 w - t_2 - 2t_1 + \sqrt{12w(t_1 + t_2)(1 - \alpha)\Theta + \theta_1^2 w^2 - 2\theta_1 w(t_2 + 2t_1) + (t_2 + 2t_1)^2}}{2w}$$

If we set $\alpha = x^H = \frac{t_1 + 2t_2}{3(t_1 + t_2)}$ and equate the two best response functions, the only solution to the above equation that also satisfies the non-negativity constraints of the model is that $\theta_1^* = \theta_2^* = \Theta$.

Therefore,

$$p_i^* = \frac{w(3 + 2\Theta + \Theta) - t_i - 2t_j}{3(1 + \Theta)} = w - \frac{t_i + 2t_j}{3(1 + \Theta)} = w - \frac{t_i + 2t_j}{3(TAC)} \rightarrow p_i^* = p_i^H$$

$$s_i^* = \frac{(1 + \Theta) \left(\frac{(\Theta - \Theta)w + t_i + 2t_j}{3(t_i + t_j)} \right)}{1 + \Theta} = \frac{(1 + \Theta) \left(\frac{t_i + 2t_j}{3(t_i + t_j)} \right)}{1 + \Theta} = \frac{t_i + 2t_j}{3(t_i + t_j)} \rightarrow s_i^* = s_i^H$$

■

As such, when $\alpha = x^H$, individual processor profit and sector-wide welfare outcomes are also equal to those that arise in the harvester-only IFQ equilibrium. In other words, processors are no better off with processor-allocated quota than without when $\alpha = x^H$, and rents are not reallocated from the harvesting sector to the processing sector (Figure 3.7), contrary to what we'd expect if processors lease quota at the market quota price (Milon and Hamilton, 2002). If quota holdings are used to obtain market share, gains by one processor come at the expense of the other, and rent transfers only occur when quota holdings produce asymmetry in the ex-vessel market.

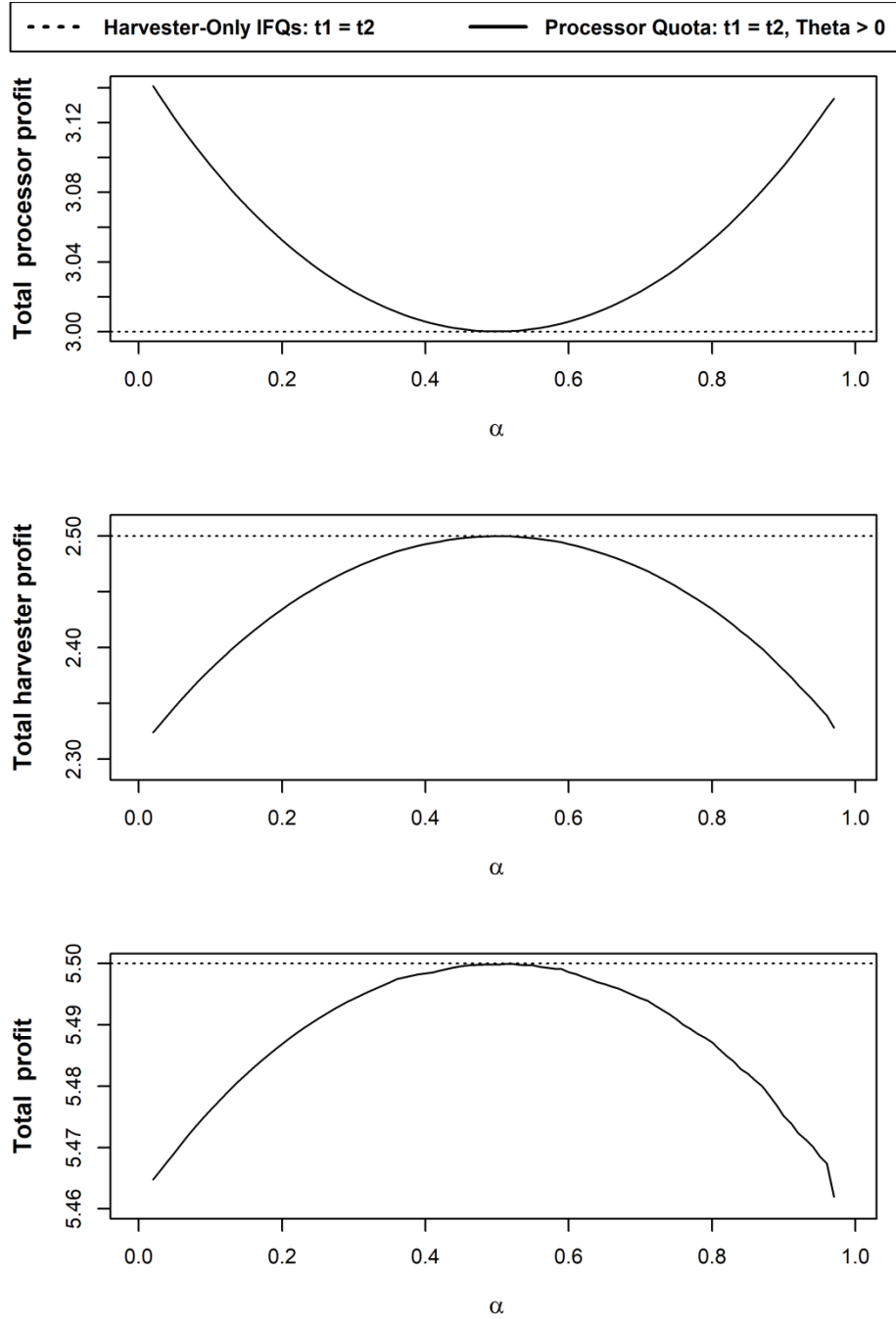


Figure 3.7: Equilibrium total processor profit, total harvester profit, and total profit from processor-allocated quota model for $\alpha \in [0, 1]$, when $\Theta = 0.25, w = 5, t_1 = t_2 = 3$. The dotted lines illustrate the equilibrium under harvester-only IFQs.

As α moves away from one-half, processor-allocated quota generates distortions in market outcomes compared to harvester-only IFQs when per-unit travel costs are homogenous (Figure 3.6). For all values of α other than one-half, asymmetry exists between the two processors as one processor has an advantage, controlling a greater share of the total processor quota allocation. Figure 3.6 illustrates how the equilibrium changes as α increases from zero (Processor 1's allocation is zero) to $\alpha = 1$ (Processor 1 receives the entire processor quota allocation). As α increases, Processor 1's optimal quota match rate increases while the optimal ex-vessel price offered decreases. With greater access to quota, they are able to obtain a larger market share despite their quota constraint while offering a lower ex-vessel price. Conversely, Processor 2 controls a decreasing portion of the processor-allocated quota and therefore must offer a higher ex-vessel price to compete for landings, and secures a lower market share.

When $t_1 = t_2$, a processor is able to earn a higher profit if they have an advantage in quota holdings, while the disadvantaged processor earns lower profit (Figure 3.6). Asymmetry in the market reduces price competition, so the increase in profit to the advantaged processor outweighs the decrease to the disadvantaged processor and the total processing sector profit increases as α moves away from 0.5 (Figure 3.7). As one processor gains quota advantage over the other, the harvesting sector is worse off (Figure 3.7). All vessels that deliver to the disadvantaged processor would do better under harvester-only IFQs or $\alpha = 0.5$, while the advantaged processor can offer vessels a higher revenue, so the vessels that are closer to this processor are better off. Some vessels that are closer to the disadvantaged processor will choose instead to deliver to the processor that has the quota advantage, with those on the margin earning lower profit than in a symmetric market. Deadweight loss is generated in the fishery when vessels deliver to a processor that is not their

lowest travel cost alternative, which occurs increasingly as inequality in processor quota holdings grows. Therefore, total rents in the fishery (the sum of total processing profit and total harvesting profit) generally decrease as α moves away from 0.5, indicating a loss in overall efficiency in the fishery relative to harvester-only IFQs.

3.3.2 *Heterogeneous Per-Unit Travel Costs*

Now we consider the case where per-unit travel costs to each processor differ, such that $t_1 \neq t_2$. Perhaps one processor is closer to the fishing grounds, or harvester exit after implementation of IFQs disproportionately affected the two processors. In this situation, one processor has a locational advantage over the other, and the differences in per-unit travel costs generate asymmetry in the market. We parameterize the model to explore comparative statics, examining the case where it is three times as costly for vessels to travel to Processor 1 as Processor 2 (Figure 3.8).³² In an ex-vessel market with no processor-allocated quota (harvester-only IFQs), the asymmetry in per-unit travel costs allows Processor 2 to capture more than half the market in equilibrium (Figure 3.8). In accordance with the theorem presented in the previous subsection, the equilibrium ex-vessel prices and market outcomes that arise under a harvester-only IFQ market are equal to those in an ex-vessel market with processor-allocated quota if $\alpha = x^H$. Again, in this case, we see no reallocation of rents from the harvesting sector to the processing sector relative to harvester-only IFQs (Figure 3.9).

³² We choose a fairly extreme dichotomy in per-unit travel costs in order to facilitate straightforward visualization of changes in equilibrium.

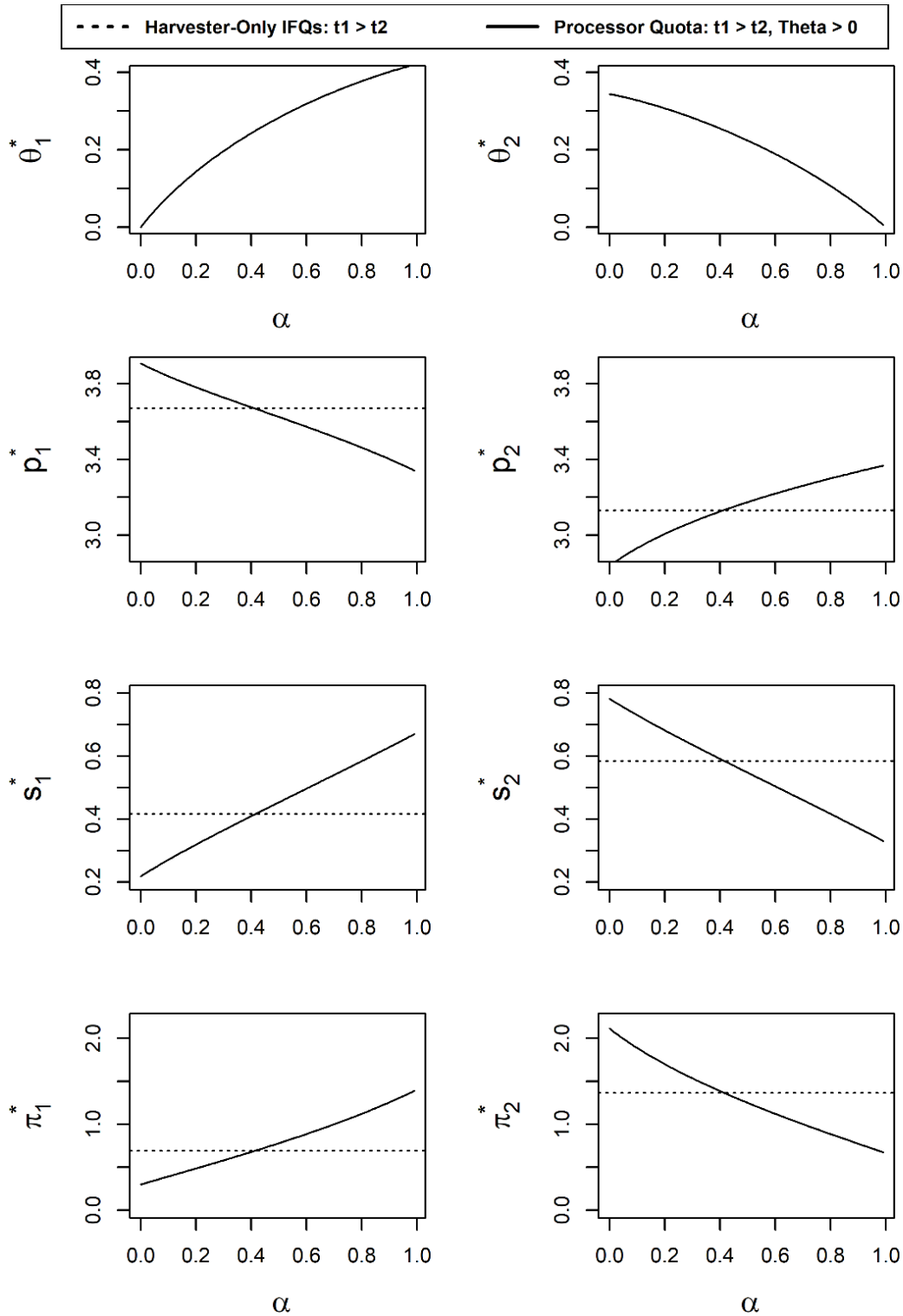


Figure 3.8: Processors' equilibrium quota match rates (θ_1^*, θ_2^*), prices (p_1^*, p_2^*), market shares (s_1^*, s_2^*), and profits (π_1^*, π_2^*) for $\alpha \in [0, 1]$, when $\Theta = 0.25, w = 5, t_1 = 3, t_2 = 1$. The dotted lines illustrate the equilibrium under harvester-only IFQs.

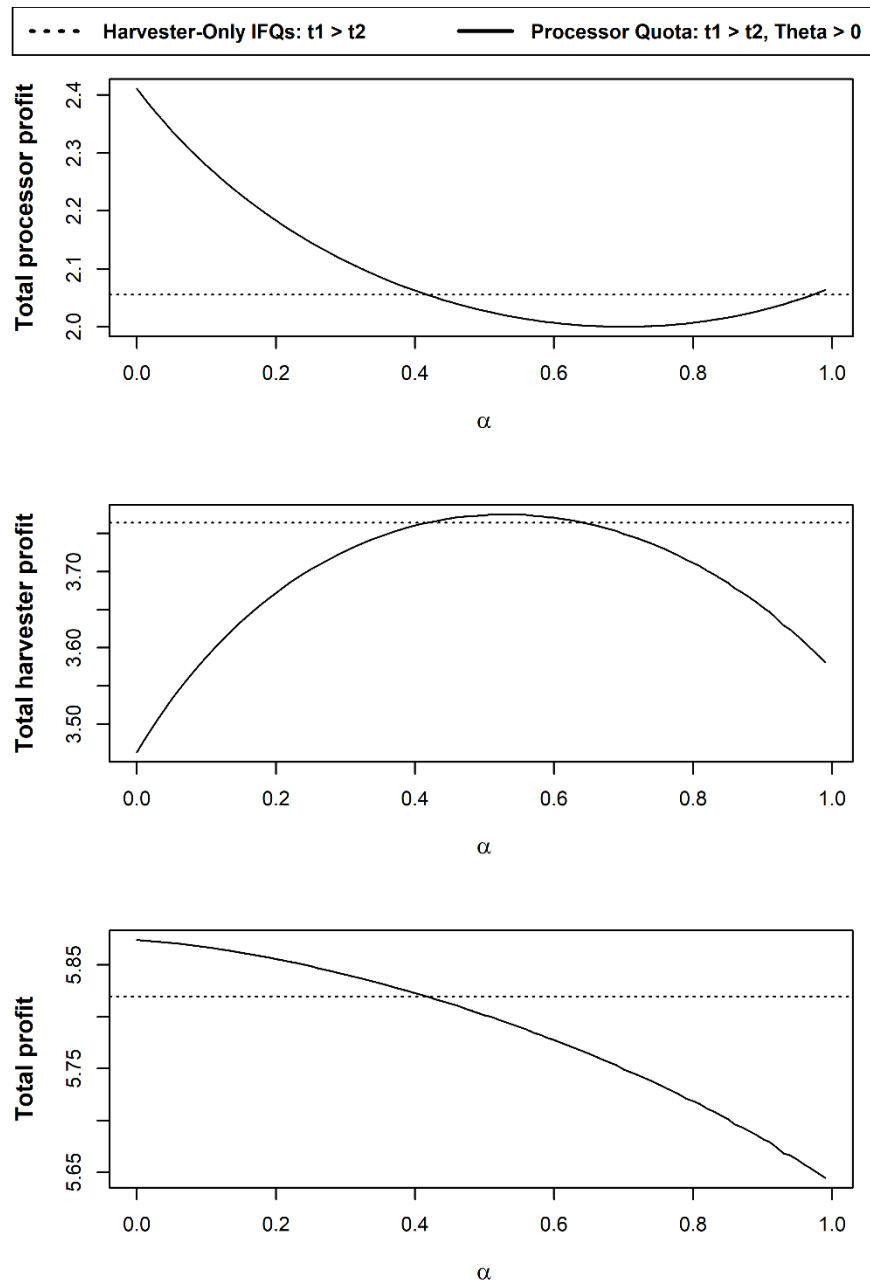


Figure 3.9: Equilibrium total processor profit, total harvester profit, and total profit from processor-allocated quota model for $\alpha \in [0, 1]$, when $\Theta = 0.25$, $w = 5$, $t_1 = 3$, $t_2 = 1$. The dotted lines illustrate the equilibrium under harvester-only IFQs.

Comparative statics as α varies between 0 and 1 are similar to those outlined for the case of symmetric per-unit travel costs. As α approaches zero, Processor 2 has an increasing advantage in quota allocation, which allows them to secure a larger market share and increase their profit by offering a higher quota match rate with a lower ex-vessel price (Figure 3.8). As the processor with the locational advantage is better able to utilize processor-allocated quota to increase profits, the processing sector as a whole is generally better off as this processor acquires more of the quota allocation. With this parameterization, processor-allocated quota can actually lead to rent transfers from processors to harvesters if the processor with the location disadvantage has a quota advantage. Allocating more quota to Processor 1 (with the location disadvantage), such that $\alpha > x^H$, counteracts the asymmetry in travel costs and increases total harvesting sector profit, but only up until a certain point, then total harvesting profit begins to decrease again as too many vessels are incurring a higher travel cost to deliver to this processor. As Processor 2 is the lower travel cost alternative for most vessels, efficiency in the fishery increases as α approaches zero (Figure 3.9); however, this efficiency is associated with increased inequality that could have adverse long-run effects.

3.4 Policy Application

In the previous sections, we developed a model of the ex-vessel market that incorporates processor-allocated harvesting quota as a tool for securing market share. We explored how processor-allocated quota can impact ex-vessel market dynamics and the welfare of fishery participants relative to a harvester-only IFQ system, particularly focusing on how the equilibrium changes as the distribution of quota between the two processors, α , changes. In this section, we consider this model in the context of a specific policy, namely the use of processor-allocated harvesting quota

to promote community stability through assisting processors in maintaining their market share through a transition to IFQs. Promoting stability in processing activity at a land-based plant could have community benefits particularly if processing plants are a source of local employment, processors distribute quota to local vessel owners, and if the community has other fishery-related businesses that support local harvesting and processing.

We assume that fishery managers are concerned of regional shifts in participation following implementation of IFQs in a fishery, which could occur due to consolidation in the harvesting sector that disproportionately affects processors, or if IFQs curb derby fishing and provide vessels more flexibility in location and timing of harvesting. To mitigate these effects, managers allocate a portion of harvesting quota to processors to help maintain market share. In most IFQ programs, quota is initially allocated to participants based on historical participation in the fishery, as this is the most politically feasible method of quota distribution. Therefore, we assume that individual processors are allocated quota according to their pre-IFQ market share, such that $\alpha = x^{pre}$. We characterize the pre-IFQ market as consisting of two homogenous processors with the same per-unit travel costs. In the pre-IFQ equilibrium, each processor offers the same ex-vessel price and acquires half of the market (Figure 3.10). With the implementation of IFQs, we assume that the distribution of vessels has shifted such that it is three times as costly for vessels to travel to Processor 1 ($t_1' = 3t_1$). Under a harvester-only IFQ system, Processor 2's location advantage allows them to attract vessels from Processor 1, securing more than half of the market (Figure 3.10).

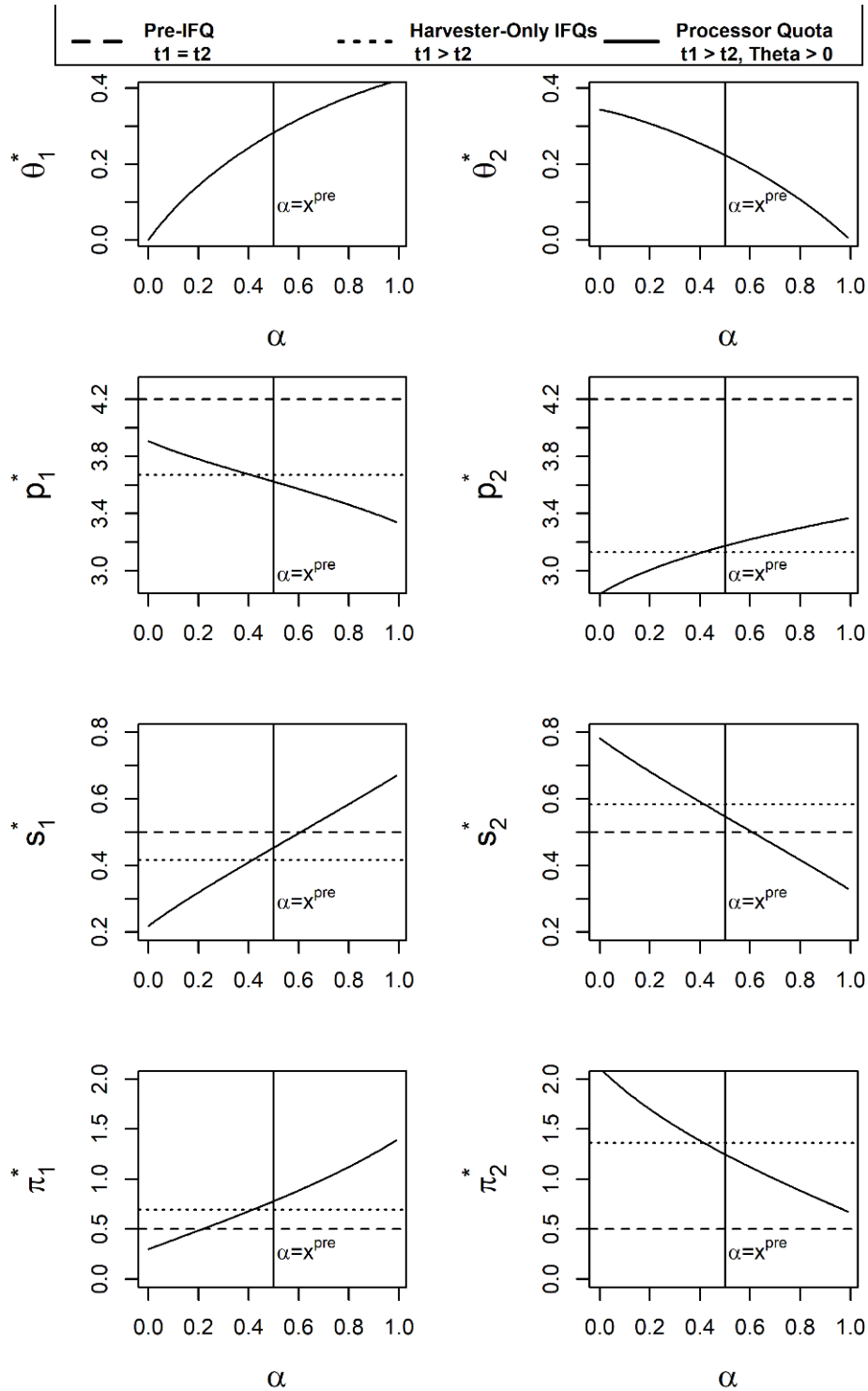


Figure 3.10: Pre-IFQ equilibrium (dashed line) when $TAC = 1.25, w = 5, t_1 = 1, t_2 = 1$.

Harvester-only IFQ equilibrium (dotted line) when $t_1' = 3$, and all other variables are unchanged. Processor-allocated quota equilibrium quota match rates (θ_1^*, θ_2^*) , prices (p_1^*, p_2^*) , market shares (s_1^*, s_2^*) , and profits (π_1^*, π_2^*) for $\alpha \in [0, 1]$, when $\Theta = 0.25, t_1' = 3$.

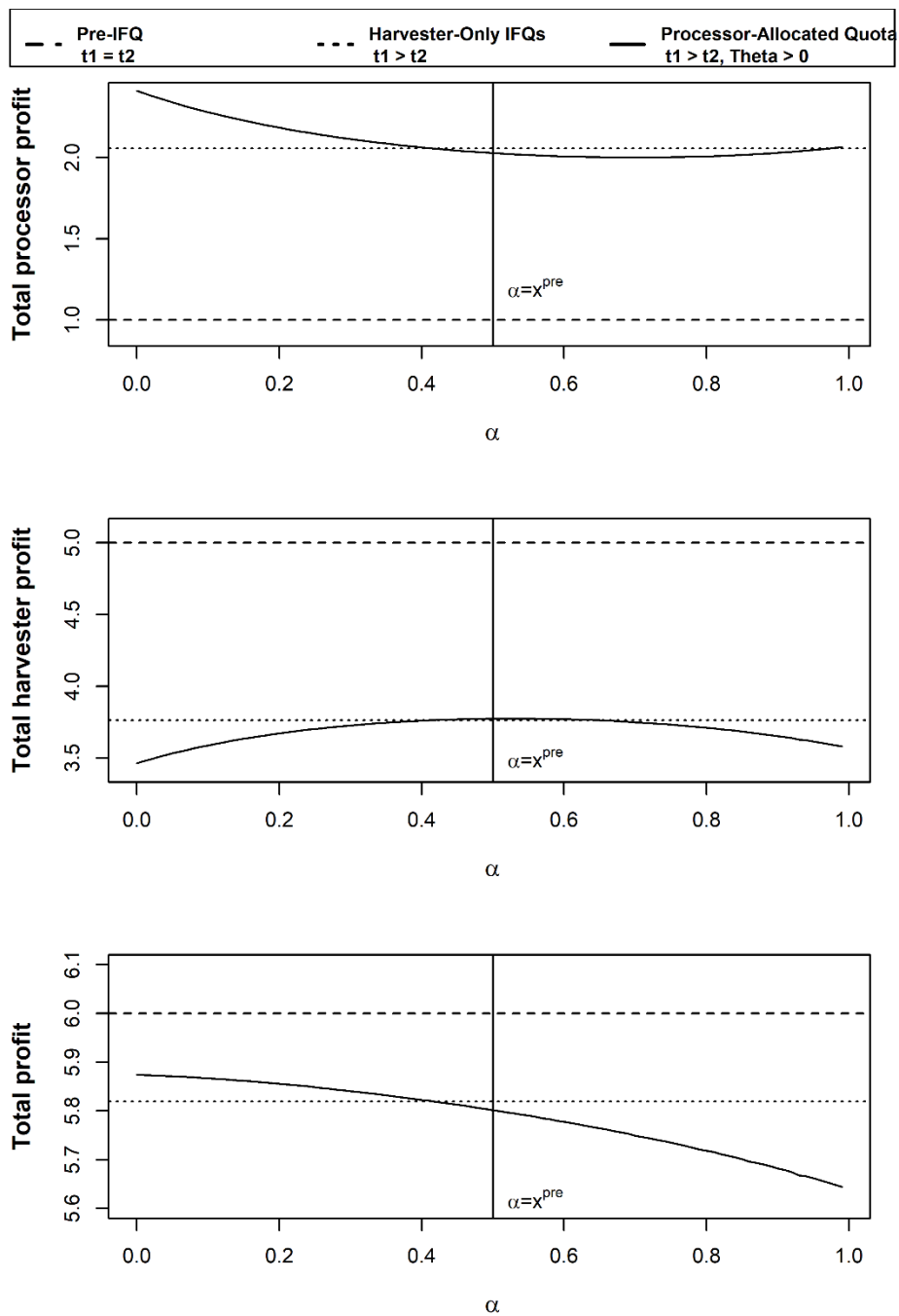


Figure 3.11: Pre-IFQ equilibrium (dashed line) when $TAC = 1.25, w = 5, t_1 = 1, t_2 = 1$.

Harvester-only IFQ equilibrium (dotted line) when $t_1' = 3$, and all other variables are unchanged. Equilibrium total processor profit, total harvester profit, and total profit from processor-allocated quota model for $\alpha \in [0, 1]$, when $\Theta = 0.25, t_1' = 3$.

If fishery managers allocated processors quota in accordance with their pre-IFQ market share ($\alpha = x^{pre} = 0.5$), Processor 1 is able to utilize their quota allocation to secure more supply of raw fish than they would under harvester-only IFQs (Figure 3.10). They are not able to fully capture their pre-IFQ market share; however, processor-allocated quota allows them to mitigate some of the loss in landings they would encounter under harvester-only IFQs. In practice, setting the correct α to meet community stability goals could prove challenging. Initial quota allocations are generally based on historical participation in the fishery during some control period. The control period is generally set far enough in advance of program implementation to avoid incentivizing participants to increase their operations in an effort to obtain a larger quota allocation. However, if historical participation during the control period is not representative of current participation, then processor-allocated quota may promote shifting market share in a way that is not reflective of current processing investments in the fishery, which could hinder the effectiveness of processor-allocated quota as a tool for community preservation. In addition, if vertically-integrated processors are present in a fishery, they may obtain more quota holdings through their vessels' initial allocations, which could impact the distribution of overall processor quota holdings between the two processors such that $\alpha \neq x^{pre}$.

One of the major concerns regarding processor-allocated harvesting quota was that it would promote increases in market power by the processing sector. These concerns are amplified if regional shifts in participation following the introduction of IFQs lead to increased market segmentation absent of processor-allocated quota. In the scenario outlined above, it became more expensive for vessels to travel to Processor 1 under IFQs, which increased regional differentiation in the ex-vessel market. Each processor earns higher profit under both IFQ regimes relative to pre-

IFQs, even though Processor 1 secures less of the market. The opposite would be true if the travel cost decreased to one of the processors, leading to increased spatial competition under IFQs, which has been observed in some fisheries (Fell and Haynie, 2013). While other factors may be influencing bargaining power in the ex-vessel market, it is important for fishery managers to consider how regional impacts of IFQs may affect ex-vessel market power when deciding whether to allocate a portion of harvesting quota to land-based processors.

3.5 Conclusion

In this study, we develop a model of the ex-vessel market that incorporates processor-allocated harvesting quota in a novel way, considering processor use of quota to secure landings rather than to receive a lump sum from leasing their quota assets. We allow for two sources of asymmetry in the model: differences in per-unit travel costs to each processor, and differences in quota holdings. In cases where processor-allocated quota is the only source of heterogeneity between processors, losses in overall efficiency are observed as well as transfers of rents from harvesters to processors. However, only the processor with the quota advantage is better off with processor-allocated quota while the other processor experiences profit loss. In cases where regional asymmetry exists as well, processor-allocated quota can counteract that asymmetry under certain fishery conditions, leading to higher total harvesting sector profits than a harvester-only IFQ system for a range of α . Efficiency generally increases as the regionally advantaged processor also gains a quota advantage; however, with these efficiency gains comes increased inequality, which could lead to exit of harvesters and the disadvantaged processor in the long term.

Overall, processor-allocated quota tends to foster anticompetitive behavior by processors when asymmetry in processor holdings is high. The initial allocation process is important for achieving policy goals and preventing unintended shifts in market power. If the goal of processor-allocated quota is to assist processors in achieving their pre-IFQ market share, then quota allocations to individual processors should be reflective of pre-IFQ conditions, which may be difficult to implement in practice for reasons including vertical integration and standards for setting appropriate control periods. In addition, it is important to consider how the regional impacts of IFQs may affect ex-vessel market segmentation. In cases where IFQs will likely lead to increased regional differentiation, other methods to promote community stability may be preferred.

This study is an important step in developing intuition of ex-vessel market dynamics and offers additional insights into effects of processor-allocated harvesting quota. This is a significant contribution to the literature and for the development of fishery management policy for several reasons. First, we observe processors using quota holdings in this manner in the only fishery to-date that has implemented processor-allocated harvesting quota, the shoreside Pacific whiting fishery. Second, given the increased consideration of this policy over the last decade, processor-allocated harvesting quota is likely to continue to be considered in the design of future catch share programs. The process of initially allocating quota in IFQ programs is already contentious given the implications on rent distribution in the fishery. Increasing our understanding of how allocating quota to processors can distort market outcomes is important for informing this process. Third, this model generates intuition that extends beyond processor-allocated quota to any fishery that allows processors to own harvesting quota either through allocations to processor-owned vessels or through the ability to purchase an allocation of harvesting quota.

However, the insights developed in this paper should be interpreted and generalized with some caution. By parameterizing the model, we limit our ability to generalize these results outside our chosen model calibration. Our current work with this model involves continuing to formalize the results we observe in this numerical analysis. It is also unclear to what extent these market distortions will persist in the long run. Moreover, in this study, we narrow our focus to specific aspects of the transition to IFQs, assuming away other complexities that may exist in the fishery. This model provides a baseline for incorporating a number of extensions. Processors costs of production would introduce another source of asymmetry between processors, and incorporating fixed costs would provide intuition around how inequality in processor quota holdings may generate exit of disadvantaged processors in the sector. In addition, allowing each processor to offer a variety of match rates to delivering vessels would be more reflective of the dynamics observed in the shoreside Pacific whiting fishery (Guldin, Chapter 2), and assist in analyzing the source of these differences. It would also be interesting to consider how the outcomes of this model change when the TAC does not bind (i.e., the market is not covered). Finally, a key question that arises in the discussion of allocating harvesting quota to processors is how much of the TAC should be allocated to processors. Wilen (2009) notes that the various allocation alternatives considered for shoreside Pacific whiting fishery were arbitrary and not based on measured losses. Extending this model to consider comparative statics associated with changing Θ would yield additional insights important to management.

BIBLIOGRAPHY

- Anderson, C. M., M. J. Krigbaum, M. C. Arostegui, M. L. Feddern, J. Z. Koehn, P. T. Kuriyama, C. Morrisett, C. I. Allen Akselrud, M. J. Davis, C. Fiamengo, A. Fuller, Q. Lee, K. N. McElroy, M. Pons, and J. Sanders. 2018a. "How commercial fishing effort is managed." *Fish and Fisheries*, 20: 268-285.
- Anderson, C. M., J. Meredith, R. G. Felthoven, and M. Fey. 2018b. "The Distribution of Fishing Revenues Among North Pacific Regions and Communities." *Marine Fisheries Review*, 80(2): 1-16.
- Anderson, J. L., C. M. Anderson, J. Chu, J. Meredith, F. Asche, G. Sylvia, M. D. Smith, D. Anggraeni, R. Arthur, A. Guttormsen, J. K. McCluney, T. Ward, W. Akpalu, H. Eggert, J. Flores, M. A. Freeman, D. S. Holland, G. Knapp, M. Kobayashi, S. Larkin, K. MacLauchlin, K. Schnier, M. Soboil, S. Tveteras, H. Uchida, and D. Valderrama. 2015. "The Fishery Performance Indicators: A Management Tool for Triple Bottom Line Outcomes." *PLoS ONE*, 10(5):e0122809.
- Berger, A. M., C. J. Grandin, I. G. Taylor, A. M. Edwards, and S. Cox. 2017. "Status of the Pacific Hake (whiting) stock in U.S. and Canadian waters in 2017." Prepared by the Joint Technical Committee of the U.S. and Canada Pacific Hake/Whiting Agreement, National Marine Fisheries Service and Fisheries and Oceans Canada, 202 p.
- Birkenbach, A. M., D. J. Kaczan, and M. D. Smith. 2017. "Catch Shares Slow the Race to Fish." *Nature*, 544: 223-226.
- Carothers, C. 2008. Rationalized out: discourses and realities of fisheries privatization in Kodiak, Alaska. In M. Lowe and C. Carothers (Editors), *Enclosing the fisheries: people, places, and power*. Am. Fish. Soc. Symp. 69: 55–74.
- Carothers, C., D. Lew, and J. Sepez. 2010. "Fishing rights and small communities: Alaska halibut IFQ transfer patterns." *Ocean & Coastal Management*, 53: 518–523.
- Casey, K. E., C. M. Dewees, B. R. Turris, and J. E. Wilen. 1995. "The Effects of Individual Vessel Quotas in the British Columbia Halibut Fishery." *Marine Resource Economics*, 10(3): 211-230.
- Crutchfield, J. A. 1956. "Common Property Resources and Factor Allocation." *The Canadian Journal of Economics and Political Science/Revue Canadienne d'Economique et de Science Politique*, 22(3): 292-300.
- Errend, M. N., L. Pfeiffer, E. Steiner, M. Guldin, A. Warlick. 2019. "Economic Outcomes for Harvesters under the West Coast Groundfish Trawl Catch Share Program: Have Goals and Objectives Been Met?" *Coastal Management*, 46(6): 564-586.

- Fell, H. 2009. "Ex-vessel Pricing and IFQs: A Strategic Approach." *Marine Resource Economics*, 24(4): 311-328.
- Fell, H., and A. C. Haynie. 2010. "Estimating Time-Varying Bargaining Power: A Fishery Application." *Economic Inquiry*, 49(3): 685-696.
- Fell, H., and A. C. Haynie. 2013. "Spatial Competition with Changing Market Institutions." *Journal of Applied Econometrics*, 28(4): 702-719.
- GAO (U.S. General Accounting Office). 2004. "Individual Fishing Quotas: Methods for Community Protection and New Entry Require Periodic Evaluation." Report to Congressional Requesters, February 2004.
- Gauvin, J. R., J. M. Ward, and E. E. Burgess. 1994. "Description and Evaluation of the Wreckfish (*Polyprion americanus*) Fishery under Individual Transferable Quotas." *Marine Resource Economics*, 9(2): 99-118.
- Geen, G., and M. Nayar. 1988. "Individual Transferable Quotas in the Southern Bluefin Tuna Fishery: An Economic Appraisal." *Marine Resource Economics*, 5(4): 365-387.
- Gordon, H. S. 1954. "The Economic Theory of a Common-Property Resource: The Fishery." *The Journal of Political Economy*, 62(2): 124-142.
- Grandin, C. J., A. C. Hicks, A. M. Berger, A. M. Edwards, N. Taylor, I. G. Taylor, and S. Cox. 2016. "Status of the Pacific Hake (whiting) Stock in U.S. and Canadian Waters in 2016." Prepared by the Joint Technical Committee of the U.S. and Canada Pacific Hake/Whiting Agreement, National Marine Fisheries Service and Fisheries and Oceans Canada. http://www.cio.noaa.gov/services_programs/prplans/pdfs/ID334_Final_PacHake2016.pdf.
- Grossman, G. M., and C. Shapiro. 1984. "Informative Advertising with Differentiated Products." *The Review of Economic Studies*, 51(1): 63-81.
- Guldin, M., and C. M. Anderson. 2018. "Catch Shares and Shoreside Processors: A Costs and Earning Exploration into the Downstream Sector." *Marine Resource Economics*, 33(3): 289-307.
- Guldin, M., E. Steiner, A. Warlick, and J. Leonard. 2017. "Economic Data Collection Program: First Receiver and Shorebased Processor Report (2009-2015)." National Marine Fisheries Service, Northwest Fisheries Science Center, Seattle, WA. https://www.nwfsc.noaa.gov/research/divisions/fram/documents/EDC_First_Receiver_Shorebased_Processor_Report_June_2017.pdf.
- Guldin, M., A. Warlick, M. N. Errend, L. Pfeiffer, and E. Steiner. 2019. "Shorebased Processor Outcomes Under Catch Shares." *Coastal Management*, 46(6): 587-602.

- Hackett, S. C., M. J. Krachey, S. Brown, and D. Hankin. 2005. "Derby Fisheries, Individual Quotas, and Transition in the Fish Processing Industry." *Marine Resource Economics*, 20(1): 47-60.
- Halvorsen, R. 2004. Oral testimony made before the U.S. Senate Committee on Commerce, Science, and Transportation hearings on the Economic Implications of Seafood Processor Quotas, February 25.
- Halvorsen, R., F. Khalil, J. Lawarree. 1999. "Inshore Sector Catcher Vessel Cooperatives in the Bering Sea/Aleutian Islands Pollock Fisheries." Discussion Paper prepared for the North Pacific Management Council, September 1999.
- Haynie, A. C. 2014. "Changing usage and value in the Western Alaska Community Development Quota (CDQ) program." *Fisheries Science*, 80: 181-191.
- Heckman, J. J. 1981. Heterogeneity and state dependence. In S. Rosen (Editor), *Studies in Labor Markets*, University of Chicago Press, Chicago, IL.
- Holland, D. S. 2016. "Development of the Pacific Groundfish Trawl IFQ Market." *Marine Resource Economics*, 31(4): 454-464.
- Holland, D. S., and K. Norman. 2015. "The Anatomy of a Multispecies Individual Fishing Quota (IFQ) 'Market' in Development." NOAA Technical Memorandum NMFS-F/SPO-158.
- Holland, D. S., and J. G. Sutinen. 2000. "Location Choice in New England Trawl Fisheries: Old Habits Die Hard." *Land Economics*, 76(1): 133-149.
- Homans, F. R. and J. E. Wilen. 2005. "Markets and rent dissipation in regulated open access fisheries." *Journal of Environmental Economics and Management*, 49(2): 381-404.
- Hotelling, H. 1929. "Stability in Competition." *The Economic Journal*, 39(153): 41-57.
- Liebcap, G. D. 2007. "Assigning Property Rights in Common Pool: Implications of the Prevalence of First-Possession Rules for ITQs in Fisheries." *Marine Resource Economics*, 22(4): 407-423.
- Matulich, S. C. 2010. "Stranded Capital in Fisheries: The Pacific Coast Groundfish/Whiting Case: Comment." *Marine Resource Economics*, 25(1): 121-128.
- Matulich, S. C., and M. L. Clark. 2003. "North Pacific Halibut and Sablefish IFQ Policy Design: Quantifying the Impacts on Processors." *Marine Resource Economics*, 18(2): 149-166.
- Matulich, S. C., R. C. Mittelhammer, and C. Reberte. 1996. "Toward a More Complete Model of Individual Transferable Fishing Quotas: Implications of Incorporating the Processing Sector." *Journal of Environmental Economics and Management*, 31(1): 112-128.

- Matulich, S. C., and M. Sever. 1999. "Reconsidering the Initial Allocation of ITQs: The Search for a Pareto-Safe Allocation between Fishing and Processing Sectors." *Land Economics*, 745(2): 203-219.
- McCay, B. J. 2004. "ITQs and community: An essay on environmental governance." *Agricultural and Resource Economics Review*, 33(2): 162-170.
- McEvoy, D. M., S. Brandt, N. Lavoie, and S. Anders. 2009. "The Effects of ITQ Management on Fishermen's Welfare When the Processing Sector Is Imperfectly Competitive." *Land Economics*, 85(3): 470-484.
- McFadden, D. 1973. Conditional Logit Analysis of Qualitative Choice Behavior. In P. Zarembka (Editor), *Frontiers in Econometrics*, Academic Press, 105-142.
- McFadden, D., and K. Train. 2000. "Mixed MNL Models for Discrete Response." *Journal of Applied Econometrics*, 15: 447-470.
- Meurer, M., and D. O. Stahl. 1994. "Informative advertising and product match." *International Journal of Industrial Organization*, 12: 1-19.
- Milon, J., and S. Hamilton. 2002. "A Comparative Analysis of Alternative Rationalization Models for the Bering Sea/Aleutian Islands (BSAI) Crab Fisheries." Paper contracted by the North Pacific Fishery Management Council, Anchorage, AK.
- Montgomery, W. D. 1972. "Markets in Licenses and Efficient Pollution Control Programs." *Journal of Economic Theory*, 5: 395-418.
- Olson, J. 2011. "Understanding and contextualizing social impacts from the privatization of fisheries: An overview." *Ocean & Coastal Management*, 54: 353-363.
- PFMC (Pacific Fishery Management Council) and NMFS (National Marine Fisheries Service). 2010. "Rationalization of the Pacific Coast Groundfish Limited Entry Trawl Fishery; Final Environmental Impact Statement Including Regulatory Impact Review and Initial Regulatory Flexibility Analysis." https://www.pcouncil.org/wp-content/uploads/1_Pacific-Coast-Groundfish-Limited-Entry-Trawl-Fishery-FEIS.pdf.
- PFMC and NMFS. 2016. "Draft Appendix B Additional Management Measure Analysis and New Management Measures Analysis 2017-2018 Groundfish Harvest Specifications of Management Measures Including Changes to Groundfish Stock Designations (Amendment 27 to Pacific Coast Groundfish Fishery Management Plan)." http://www.pcouncil.org/wp-content/uploads/2016/06/G4_Att5_DraftAppB_JUN2016BB.pdf.
- PFMC and NMFS. 2017. "West Coast Groundfish Trawl Catch Share Program Five Year Review." https://www.pcouncil.org/wp-content/uploads/2018/12/Trawl_CSR_2017_MainDoc_Final.pdf

- Powell, R. 2004. Oral testimony made before the U.S. Senate Committee on Commerce, Science, and Transportation hearings on the Economic Implications of Seafood Processor Quotas, February 25.
- Russell, S. M., K. Sparks, A. Arias-Arthur, and A. Varney. 2014. "The Pacific Groundfish Fishery Social Study: An Initial Theme Based Report." National Marine Fisheries Service, Northwest Fisheries Science Center, Seattle, WA.
<https://www.nwfsc.noaa.gov/research/divisions/cb/ecosystem/humandim/documents/The%20Pacific%20Groundfish%20Fishery%20An%20Initial%20Theme%20Based%20Report.pdf>
- Steiner, E., M. Guldin, A. Warlick, L. Pfeiffer. 2017. "Economic Data Collection Program: Catcher Vessel Report (2009-2015)." National Marine Fisheries Service, Northwest Fisheries Science Center, Seattle, WA.
https://www.nwfsc.noaa.gov/research/divisions/fram/documents/EDC_Catcher_Vessel_Report_June_2017.pdf
- Warlick, A., E. Steiner, and M. Guldin. 2018. "History of the West Coast Groundfish Trawl Fishery: Tracking Socioeconomic Characteristics across Different Management Policies in a Multispecies Fishery." *Marine Policy*, 93: 9-21.
- West Coast Seafood Processors Association (WCSPA). 2007. Public Comment submitted for PFMC Meeting, November 2007.
- Wilen, J. E. 2008. "Why Giving Harvester Quota to Processors is Bad Policy." Discussion points for PFMC Meeting, November 2008.
- Wilen, J. E. 2009. "Stranded Capital in Fisheries: The Pacific Coast Groundfish/Whiting Case." *Marine Resource Economics*, 24(1): 1-18.
- Young, R.D. 2004. Oral testimony made before the U.S. Senate Committee on Commerce, Science, and Transportation hearings on the Economic Implications of Seafood Processor Quotas, February 25.

Appendix A

**SUMMARY STATISTICS AND SUPPORTING FIGURES
FOR CHAPTER 2**

Table A.1: Mean values of variables in ex-vessel prices regressions shown in Table 2.2, Specifications 1 and 2 for IFQ years. Standard deviations listed in parentheses.

	Ex-vessel revenue (millions of 2015 \$)	Pounds Landed (millions)	Ex-vessel price (2015 \$)	Processor- owned Quota Pounds Transferred (millions)	N
2011	0.55 (0.49)	4.48 (3.91)	0.12 (.007)	1.75 (1.76)	31
2012	0.49 (0.48)	3.25 (3.10)	0.15 (.018)	0.99 (1.20)	32
2013	0.73 (0.63)	5.41 (4.59)	0.13 (.007)	1.68 (1.55)	25
2014	0.65 (0.64)	5.58 (5.46)	0.11 (.008)	1.40 (1.68)	25
2015	0.26 (0.23)	3.25 (2.87)	0.08 (.003)	0.69 (1.09)	21
2016	0.27 (0.29)	3.60 (4.02)	0.07 (.018)	0.66 (1.06)	30
2017	0.76 (0.56)	9.62 (7.12)	0.08 (.004)	1.63 (2.45)	22

Table A.2: Mean values of variables in ex-vessel prices regressions shown in Table 2.2, Specifications 3 and 4 for IFQ years. Standard deviations listed in parentheses.

	Ex-vessel revenue (millions of 2015 \$)	Pounds Landed (millions)	Ex-vessel price (2015 \$)	Processor- owned Quota Pounds Transferred (millions)	N
2011	0.15 (0.24)	1.15 (1.71)	0.13 (.015)	0.45 (0.61)	121
2012	0.16 (0.22)	0.99 (1.26)	0.16 (.063)	0.31 (0.43)	105
2013	0.22 (0.24)	1.56 (1.75)	0.14 (.012)	0.49 (0.63)	87
2014	0.20 (0.24)	1.68 (1.99)	0.11 (.009)	0.44 (0.62)	83
2015	0.04 (0.10)	0.49 (1.25)	0.08 (.031)	0.11 (0.48)	136
2016	0.05 (0.11)	0.68 (1.42)	0.07 (.016)	0.13 (0.39)	153
2017	0.06 (0.17)	0.78 (2.26)	0.08 (.007)	0.18 (0.60)	270

Table A.3: Mean values of variables in landings-level conditional logistic regressions shown in

Table 2.4.

Variable	Mean	Standard Deviation
Ex-vessel price (2015 cents)	11.15	3.77
Quota match rate in binding TAC years (percent)	28.89	17.36
Quota match rate in non-binding TAC years (percent)	17.81	14.43
Last landing to processor (dummy)	0.2212	0.4150
Share of landed pounds to processor last season (percent)	19.40	36.89
N (cases)	3,815	

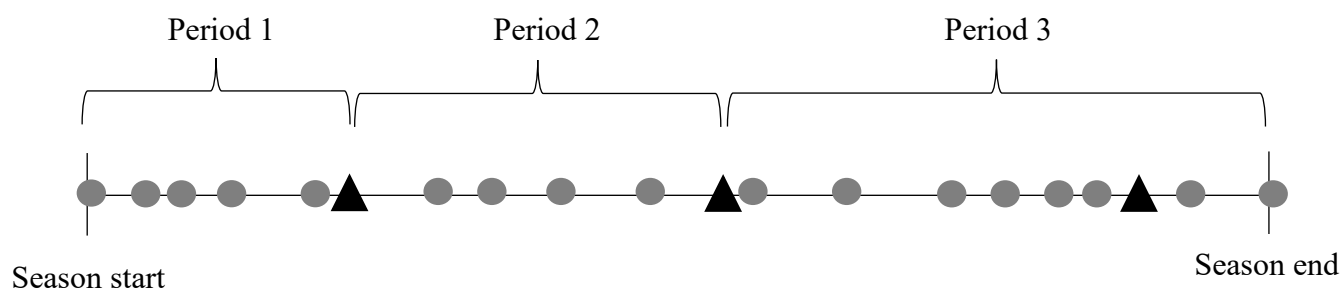


Figure A.1: Example of how backward-looking method matches quota transfers (triangles) with landings (circles) for a processor-vessel pair involving three quota transfers throughout the season.

Appendix B

ROBUSTNESS CHECKS FOR CHAPTER 2**B.1 Landings-level Mixed Logit Model**

As a robustness check, we also estimate the vessel supply decision using a mixed logit model to address several potential concerns regarding use of the conditional logistic framework outlined in subsection 2.3.6. One concern may be the assumption of independence of irrelevant alternatives (IIA), which would be violated if, for example, we believe that the relative likelihood a vessel chooses one processor over another will change based on whether an additional third processor is present. The mixed logit model relaxes the IIA assumption, allowing alternatives to be correlated. Another concern might be that the conditional logistic model does not adequately control for heterogeneity in landing decisions. The mixed logit framework allows for estimation of fixed coefficients as well as random coefficients that vary across decisions. We estimate the coefficient on $S_{i,j,t}$ as random, while considering the coefficients on ex-vessel price, quota match rate, and the lagged dependent variable to be fixed.

Summary statistics are the same as those for the conditional logistic model and are shown in Table A.2. Results from the landings-level mixed logit model are shown in Table B.1. The coefficient estimates on all variables are very similar to those estimated by the conditional logit model shown in Table 2.4. We find quota match rate to be important to vessel supply decisions only during binding TAC years with an estimated $\Delta q = 1.05$.

Table B.1: Landings-level mixed logit model (2011-2017)

Log of ex-vessel price (cents)	-0.5113 (.4753)
Quota match rate in binding TAC years (percent)	0.0105*** (.0039)
Quota match rate in non-binding TAC years (percent)	-0.0082 (.0073)
Last landing to processor (dummy)	4.000*** (.2042)
Share of landed pounds to processor last season (percent): random parameter	0.0202*** (.0013)
N (cases)	3,815
Pseudo R-squared	0.8621

***, **, * indicates significance at the 1%, 5%, and 10% levels respectively. Standard errors in parentheses.

B.2 Season-level Conditional Logistic Model

To complement the landings-level model of vessel supply detailed in subsection 2.3.6, we also model vessel supply decisions at the season level as a robustness check, particularly given the large impact of the lagged dependent variable in the landings-level model. In this case, we assume vessels make decisions prior to the season about which processors to deliver to and how to distribute deliveries throughout the season. There are a number of instances in the data where vessels appear to have a primary processor(s), but have one landing in a season with another processor. Discussions with industry indicate these “one-off” landings are generally due to scheduling or some unforeseen conflict that arises during the season. Therefore, we characterize the seasonal delivery decision as follows: the dependent variable, $y_{i,j,t}$, is 1 if vessel i lands more than once with processor j during season t and 0 otherwise, where multiple alternatives can be

chosen for each season. In nearly 80% of the cases, vessels chose only one alternative per season.

We estimate the following empirical model:

$$u_{i,j,t}^* = \alpha_j + \beta_1 \theta_{i,j,t} + \beta_2 \log(p_{i,j,t}^x) + \beta_3 s_{i,j,t} + \epsilon_{i,j,t}$$

$\theta_{i,j,t}$ and $s_{i,j,t}$ are generated as described in subsection 2.3.6. For ex-vessel price, we utilize observed or imputed prices (method described in subsection 2.3.6) to calculate weighted average seasonal ex-vessel prices for each processor-vessel pair. Summary statistics are shown in Table B.2.

Table B.2: Mean values of variables in season-level conditional logistic regression.

Variable	Mean	Standard Deviation
Ex-vessel price (2015 cents)	11.15	3.09
Quota match rate in binding TAC years (percent)	28.60	22.49
Quota match rate in non-binding TAC years (percent)	16.60	15.56
Share of landed pounds to processor last season (percent)	15.77	33.62
N (cases)	139	

Table B.3 illustrates the results from the conditional logistic model of vessels' seasonal delivery decisions. As in the landings-level model, we see that the strength of processor-vessel relationships the previous season is an important determinant of a relationship this season and ex-vessel price has no statistically significant effect on vessel supply. Similarly, quota match rate has a significant impact on vessel supply only in years when the TAC was binding. The coefficient on quota match

rate yields $\Delta q = 1.24$ on average. A likelihood-ratio test comparing the model in Table B.3 to the same estimation model excluding quota match rate rejects the null hypothesis at the 1% level.

Table B.3: Season-level conditional logistic model (2011-2017)

Log of ex-vessel price (cents)	-1.697 (1.068)
Quota match rate in binding TAC years (percent)	0.0124** (.0061)
Quota match rate in non-binding TAC years (percent)	-0.0203 (.0130)
Share of landed pounds to processor last season (percent)	0.0395*** (.0050)
N (cases)	139
Pseudo R-squared	0.4670

***, **, * indicates significance at the 1%, 5%, and 10% levels respectively. Standard errors in parentheses.