From Whales to Fish: Three Essays on Marine Resource Economics

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A dissertation

submitted in partial fulfillment of the

requirements for the degree of

Doctor of Philosophy

University of Washington

2025

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Program Authorized to Offer Degree:

Economics

University of Washington

Abstract

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My dissertation considers how marine policies aimed at protecting vulnerable human communities and endangered ecological populations impact socio-economic outcomes. The first chapter uses a discrete choice experiment to estimate how changes in tour attributes affects Salish Sea tourist willingness to pay for whale watching tours. I find that tourists are willing to pay the most to view orcas from a close viewing distance for at least 40 minutes with less boats in proximity. My sample exhibits clear heterogeneity for the number of boats in proximity and the viewing distance, which I investigated with a latent class model. My second chapter develops a theoretical model to investigate how processor centered cooperatives and processor-allocated quota impact ex-vessel prices, market share, and quasi-rents for fishery harvesters and processors post-rationalization. My third chapter analyzes a behavioral experiment of my theoretical predictions from chapter two, using experimental data collected during research sessions with undergraduates acting as fishery harvesters and processors. Fisheries rationalization through individual harvest rights increases overall industry rent while also transferring rent from the processing sector to the harvesting sector. Both my theoretical model and experiment show that fishing cooperatives and allocating some harvest rights to processors both transfer rent from the harvesting sector to the processing sector, though this this rent transfer is not split equally within the processing sector. My research shows that processor centered cooperatives and processor-allocated quota both benefit low-cost processors, but only a combined policy with both cooperatives and processor quota benefits high-cost processors in a meaningful way. Managers and researchers designing community protections for high-cost processing plants providing local jobs should carefully consider these differential impacts. My research uses several different methods, including a discrete choice experiment, a theoretical model, and a behavioral experiment, to discuss policy protections for vulnerable human and endangered animal populations.

Acknowledgments

First off, I would like to thank Dr. Chris Anderson, a better advisor and mentor than I could have hoped for. Thank you for sharing your unmatched knowledge of marine resources, letting me explore more ideas than I could count, all of the time spent theorizing about my research, and above all for listening to me and being there for me when I needed it most. Thank you to my co-advisor Dr. Alan Griffith for sharing your technical expertise and precision. I learned an enormous amount from you, and I appreciate your kindness and support. Thank you to my other committee members Dr. Xu Tan and Dr. Sunny Jardine for your time and support. I want to extend additional thanks to Dr. Melissa Knox and Dr. Hem Nalini Morzaria-Luna for their guidance with my research, especially early in my dissertation as I learned so much from both of you.

I want to acknowledge Sea Grant and NOAA for funding my research. Without this support it would not have been possible to do my own data collection, something I learned so much from and enjoyed very much. Thank you to the UW Economics department, that offered so much support, both financial and other, that greatly assisted me. To every professor that encouraged me along my journey and offered much needed kindness, thank you. Particularly, a huge thank you to Dr. Yu-chin Chen, Dr. Alan Griffith, Dr. Rachel Heath, Dr. Fahad Khalil, Dr. Jacques Lawarrée, Dr. Xu Tan, Dr. Jing Tao, Dr. Stephen Turnovsky, and Dr. Eric Zivot for your support.

Finally, I want to thank my family and friends, who tested my surveys and behavioral experiment tirelessly. A particular thank you to my mother, my father, and my lovely husband, Alex. You have all attended countless dinner lectures on my research ideas and results, to the point that you might be able to write my abstract. You have each stood by me for the excitement, the struggles, and the slog that can be research. To my mom, thank you especially for your encouragement and writing assistance from application to dissertation and every step along the way. To my dad, thank you especially for your help with my behavioral experiment, your shared love of fisheries, and your non-wavering confidence and encouragement. To my dear Alex, from joyous screaming upon my admission offer, to the t-rex cakes, it has always been you and me.

Tourist Preferences for Whale Watching and Rule Changes in the Salish Sea

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Introduction

Many wildlife tours view protected species that are subject to stringent protections. While viewing regulations are enacted to protect vulnerable wildlife (Giles and Koski, 2012), excessively strict rules can threaten local coastal economies that rely on tourism revenue (Andersen and Miller, 2006). In addition to supporting local tourism, wildlife tours can lead to positive outcomes, including: increasing tourist engagement with environmental issues after reflection (Ballantyne et al., 2018) and supporting conservation work such as anti-poaching efforts (Newsome, 2021). Balancing both positive and negative impacts of wildlife tours often necessitates estimating welfare impacts of recreational natural area use regulations, which can be difficult, especially in contexts with competing needs such as balancing wildlife conservation with tourist experience (Lewis and Newsome, 2003) or balancing competing user groups that prefer not to interact such as snowmobilers and non-snowmobilers (Mansfield et al., 2008). The economic impacts of viewing rules in multispecies contexts with competing needs, such as endangered species, have not been directly considered within the literature. We estimate the impacts of rule changes for whale watching tours in the Salish Sea (northwest Washington, U.S. and southwest British Columbia, Canada), a marine mammal rich environment.

Whale watching tours in the Salish Sea view many types of whales, including: the culturally and ecologically important Southern Resident Killer Whales (SRKW; *Orcinus orca*), transient killer whales (Bigg's killer whales), humpback whales (*Megaptera novaeangliae*), and other cetaceans such as porpoises (harbor porpoise, *Phocoena phocoena* & Dall's porpoise, *Phocoenoides dalli*) ("Pacific," 2022). Most whale watching tours aim to view larger cetaceans, such as the identical-looking transient killer whales and SRKW or humpback whales. Local coastal communities rely heavily on tourism income that is heavily dependent on whale watching opportunities; 33% of non-local tourists report they would not visit the San Juan Islands, Washington, at all if they could not view killer whales (Van Daren et al., 2019). Salish Sea whale watching tour operators range from large boats with hundreds of passengers to kayak and zodiac boat tours. Most tour operators are members of the Pacific Whale Watching Association, which shares information on whale locations and maintains a commitment to conservation ("Pacific," 2022). In addition to boat-based commercial whale watching, numerous private boaters view whales in the region. Whales travel between Washington State (U.S.) and British Columbia (Canada) waters; both countries aim to make viewing rules similar.

Salish Sea commercial whale watching vessels are subject to a range of whale specific viewing rules, with special precautions for the endangered SRKW. Different legal viewing distances exist for humpback whales, transient killer whales, and SRKW: 100 yards, 200 yards, and 300 yards, respectively in 2024. In addition to legal viewing distances, a Washington Department of Fish and Wildlife 2021 rule change limited commercial whale watching of SRKW to four hours per day July-September. Additionally, only three commercial whale watching vessels are allowed to view a group of SRKW at one time; no limit exists for the number of recreational boaters ("Commercial," 2021). Although these regulations were enacted to balance SRKW protections and eco-tourism, concerns remained that such rule changes could affect tourist preferences to go whale watching or tour quality, potentially impacting local tourist-dependent economies (Van Daren et al., 2019). Tour attribute changes such as the viewing distance, which can exhibit heterogeneity (Kessler et al., 2014), can have a large impact on demand for whale watching. We estimate the welfare effects of tour attribute levels due to recent rule changes on demand for whale watching in the Salish Sea. We anticipate that the majority of tourists would prefer to view whales from a closer distance and that tourists would be willing to pay to view non-endangered whales.

Welfare estimates, such as willingness-to-pay (WTP) for whale watching attributes, may be obtained using stated preference methods such as discrete choice experiments (DCE). Previous DCE research has guided managers by estimating consumer WTP to measure preferences for conservation fees (Shapiro, 2006), crowding effects (Ávila-Foucat et al., 2013), and wildlife distance and observability (Semeniuk et al., 2009; Kessler et al., 2014; Lee et al., 2019). We use the results from our 2021 nationwide survey of potential Salish Sea whale watchers to estimate tourist WTP for: type of whale viewed, viewing distance, number of boats in proximity, time spent with whales, company environmental commitment, and cost attributes. In addition to estimating a representative consumer model, we investigated preference heterogeneity with a latent class model. Latent class models can be used to identify groups that may be impacted by rule changes that affect tour attributes (Semeniuk et al., 2009). We assessed rule change impacts on demand for whale watching tours by estimating total willingness-to-pay (TWTP) for a range of tour specifications using our latent class model results. As a robustness check, we estimated an attribute non-attendance (ANA) model (Scarpa et al., 2009; Lew and Whitehead, 2020). We are not aware of any other studies that have used similar methods to evaluate whale watching tour attribute changes in contexts where multiple types of whales are viewed.

The rest of the paper is as follows: Section two covers background information about whale watching, the Salish Sea, and our DCE. Section three presents methods including survey design and data collection, attribute selection, empirical modeling, and estimation. Section four presents the results of the DCE, latent class grouping of the DCE, ANA model results, and demand estimation for tour specifications. Section five discusses the results, including policy implications. Section six concludes.

2. Background

2.1 Salish Sea Whale Watching

Salish Sea whale watching includes many commercial and private whale watching boats that view SRKW, transient killer whales (Bigg's killer whales), humpback whales (*Megaptera novaeangliae*), and other marine mammals. The commercial whale watching industry in the region is estimated to support 13% of all employment in San Juan Island county, Washington (Van Daren et al., 2019). As one of the few places in the continental US that regularly offers viewing of killer whales, approximately 50% of whale watchers in the Salish Sea reside over 1,000 miles from the Washington area (Andersen and Miller, 2006). We will refer to the group of potential tour participants as tourists, regardless of their residency.

While the region is known for killer whales in general, local salmon-eating and culturally-relevant SRKW are spending less time in the San Juan Islands and nearby waters than they have historically due to decreased prey availability (NOAA, 2016), while transient killer whales are spending more time in the Salish Sea since the mid-2000s (Smultea et al., 2022). Ninety percent of tours in the region view whales ("Whale," 2022a; "Whale," 2022b), and most view transient killer whales and/or humpback whales. The standard commercial whale watching package in the region typically offers 3-6 hour tours on a wide range of boat sizes. The tours may advertise the viewing of a specific whale type, but operators generally make daily choices of what whale group to view based on travel distance and the number of boats already present.

While tours usually do not view SRKW, this type of orca is most familiar to tourists; therefore, rule changes for viewing SRKW may affect overall tour demand.

Current rules for viewing whales in the Salish Sea depend upon the type of whale and whether the vessel is commercial or private. Whale watching rules exist to protect whales from harm, including boat noise that can affect whales' ability to forage, a particular concern for endangered whales like the SRKW (Ferrara et al., 2017). Legal viewing distances for transient killer whales and humpback whales are 200 and 100 yards, respectively ("Regulations," 2022). The legal side-viewing distance for SRKW in Washington is 300 yards as of 2024, though this viewing distance will increase to 1,000 yards in 2025. Commercial whale watching operators are limited to viewing SRKW in one of two 2-hour windows per day from July-September with only three commercial vessels in proximity ("Commercial," 2021). As this new regulation does not apply to private vessels, the number of vessels near SRKW could exceed three when recreational boaters are present, a common occurrence in the Salish Sea ("Soundwatch," 2022).

2.2 Whale Watching Valuation

As a starting point for evaluating proposed changes to viewing distances for SRKW, we draw on previous work describing drivers of whale watching tourism. Andersen and Miller (2006) compared pre-tour expectations and post-tour evaluations to rank what attributes tourists value the most and found that very few respondents stated they were disappointed because they didn't see killer whales or specifically SRKW. While Andersen and Miller (2006) include the viewing of non-killer whale wildlife as a memorable factor for whale watching trips, they did not break out the type of whale or type of other wildlife viewed. Barnes-Crouse (2019) measured tourist preferences for various attributes including viewing distance, the amount of viewing time, and whale protection donations.

Policy relevant attributes for whale watching tours vary based on the type of tour, regulatory context, and specific ecosystem. In addition to valuations of whale watching, welfare effects of whale policy often incorporate ecosystem benefits (Kellert, 1985), existence value (Loomis and Larson, 1994; Schwarzmann et al., 2021), and individual decision making to reduce whale harm (Bisack and Clay, 2021). Respondent-ranked attribute studies can measure tourist preferences for an attribute such as boat and passenger crowding (Torres-Matovelle and Molina-Molina, 2019) or tourist preferences for wildlife interactions such as minke whale swimming experiences (Valentine et al., 2004). Some researchers tie tourist preferences to policies such as use fee or touching wildlife (Lewis and Newsome, 2003; Ballantyne et al,. 2009). Policy implications can be more easily interpreted when accompanied by welfare estimates, especially WTP estimates (Davis et al. 2019).

Welfare estimates for whale watching and wildlife tour attributes are often measured with a discrete choice experiment (DCE) framework that asks respondents to choose one tour scenario from several options. How respondents trade off among various attributes is revealed by their choices among tour options that present different combinations of attributes in the choice experiment (Hess and Daly, 2014). Tourist preferences for viewing accessibility of wildlife can be measured using DCE, as seen for dolphin excursions (Hu et al., 2009), for whether tourists can touch stingrays (Semeniuk et al., 2009), for the humpback viewing distance compared between boat-based and shore-based tourists (Kessler et al., 2014), for WTP to view bears from the road in Yellowstone National Park (Richardson et al., 2014), and for the chance of seeing a whale on a boat tour (Lee et al., 2019). WTP for attributes such as a conservation tour fee

(Shapiro, 2006) or whale organization donation (Lee et al., 2019) can illustrate how tourists value whale and salmon conservation. Other DCE include WTP for endangered Steller Sea Lion protections and recovery scenarios (Lew et al., 2010); recreational angler valuation of wild salmon, hatchery salmon, and other game fish (Anderson and Lee, 2013); valuing park quality (Hearne and Salinas, 2002; Penn et al., 2016); and landfill placement (Das et al., 2009).

3. Methods

Utilizing an online survey, we conducted a discrete choice experiment to estimate tourist WTP estimates for whale watching attributes. We estimated overall sample WTP estimates for both a linear and non-linear specification, and we additionally estimated a latent class model to explore heterogeneity within our sample. Using our latent class model estimates, we simulated how various tour specifications would affect demand for whale watching in the Salish Sea to evaluate implications of whale watching rule changes.

3.1 Survey Design

Our survey included a DCE, a section to report whale watching history and expectations for future whale watching, and demographic questions. Prior to the DCE questions, we asked respondents to read information explaining the different attributes and levels. The information, including our “Cheap Talk” script, is included in Appendix Figure A2. Each of the five DCE questions asked respondents to choose one of three tour scenarios or an opt-out scenario of not whale watching from a boat. The survey concluded with demographic questions.

Although on-site surveys are common in recreational valuation (Kessler et al., 2014; Torres-Matovelle and Molina-Molina, 2019), we determined an online survey would reach tourists that may be in the market for whale watching beyond those that are on a tour. In addition, funding limitations required that our survey occur April-June 2021, when COVID-19 precautions limited the ability to conduct an in-person survey that represented a typical tourist population. We recruited 1,442 survey participants in the U.S. via both Facebook and Instagram social media platforms using ads created with Facebook Ad Manager[1] between April and June 2021. Ads were targeted to U.S. residents over the age of 18 with an interest in ecotourism. An example ad is included in Figure A1. The survey took approximately 10 minutes to complete; respondents had a random chance to win one of five $50 e-gift cards as a participation incentive.

While online surveys have gained popularity as a survey method that is affordable and accessible for researchers, concerns about lower response rates (Daikeler et al., 2020) and fraud (Goodrich et al., 2023) exist. In addition to a low expected return, we included several bot detection methods such as reCAPTCHA and visually screened email addresses, as recommended by Storozuk et al. (2020). We asked respondents how they reached the survey and removed responses not from our advertisement, such as responses from texted links or social media posts from previous respondents that could create a biased sample. We also removed duplicate IP address responses. Out of 1,532 completed surveys, we found zero instances of bots (likely due to a low expected return) and 90 instances of friend/family survey completion, leading to a 94% inclusion rate (see Appendix Table A1).

We targeted survey recruitment to potential whale watching tour customers, rather than aim for a representative sample of U.S. residents, in order to obtain more precise WTP estimates from a population more likely to go whale watching. To ensure that our survey reached potential whale watching tour customers specifically, our ad included the question “Do you like whales?” (a sample ad can be found in the Appendix). Facebook does not provide information on the

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[1] As Facebook owns Instagram, all ads were managed through Facebook Ad Manager. We did try google advertisements, though similar to Ali et al. (2020), we failed to obtain any views after 2 days and chose to terminate that ad campaign.

number of users who are shown an ad though they do report a "reach," the number of people determined to have reacted to the ad in some way. Our survey respondent recruitment ad reached over 264,000 people with 5,981 link clicks; we included 1,442 respondents in the final sample after eliminating incomplete surveys and other excluded surveys. While many people who clicked the link did not complete the survey, most attrition occurred around the consent form, which was likely due to a low incentive or the 10 minute length of the survey. In total, we spent $1,258 over the course of two months on advertising the survey, for an average cost of $0.87 per respondent.

Population statistics on Salish Sea commercial whale watchers are available from several onboard surveys (Andersen, 2004; Finkler and Higham, 2004; Warren, 2012; Barnes-Crouse, 2019). We report our population statistic averages along with other averages in Figure 1. The average age of Salish Sea whale watchers is approximately 45 and the average years of education is 16, or an undergraduate college degree. While all Salish Sea surveys report that more than half of onboard whale watchers are female, our sample is 84% female. Facebook targets advertising to populations with higher response rates automatically, and so likely targeted the advertising towards women. While we did not consider counteracting this, Boas et al. (2020) targeted a survey specifically to men after finding women over-represented in their original sample. Race, ethnicity, and income demographics are not commonly reported on Salish Sea whale watchers. We report our full sample statistics in Appendix Table A2.

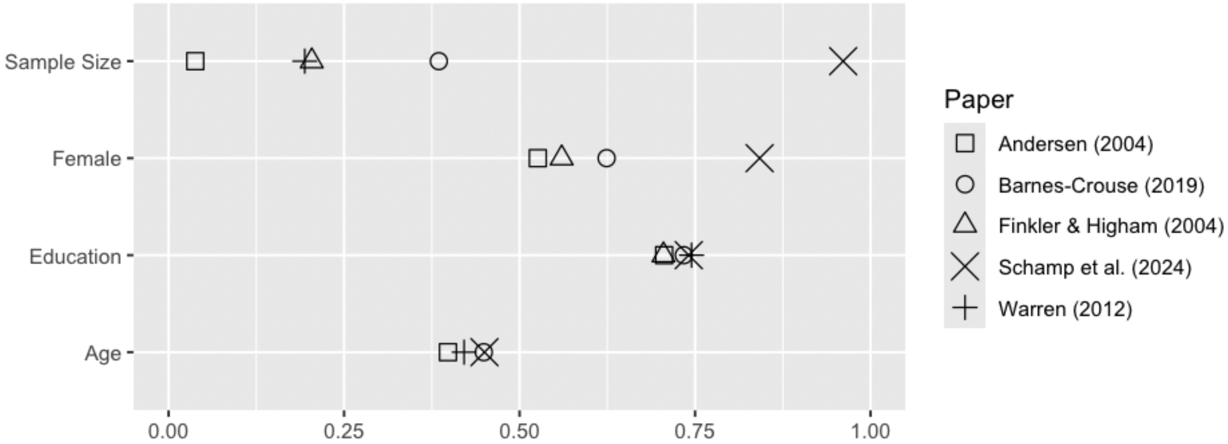

Figure 1: Salish Sea boat-based commercial whale watching sample statistics.
Note: The means are the sample size divided by 1,500, percentage of female survey respondents, years of education divided by 22, and age divided by 100, respectively. Age and was obtained from an average of each education range and is for respondents older than 16, older than 19, and older than 18 for Anderson (2004), Warren (2012), and all other papers, respectively. Education was obtained by converting the highest degree obtained to years of education.

3.2 Discrete Choice Experiment

The DCE used selected attributes, levels for each attribute, and cost levels to measure WTP in 30 questions blocked into 6 groups. We estimated parameters with a multinomial logit model for both linear and nonlinear homogeneous models. We investigated heterogeneity in preferences with a latent class model unrestricted on all non-cost attributes.

3.2.1 Attributes

The attributes selected for a DCE are the arguments in the utility function consumers use to evaluate their experience. The attributes and levels chosen for the DCE were based on previous literature (e.g., Andersen and Miller, 2006, Lee et al., 2019), on features unique to whale watching in the Salish Sea area, and to Washington State rule changes. We consulted with stakeholders to help inform study and survey design; participants included industry representatives from the Pacific Whale Watching Association (“Pacific,” 2022), resource managers from Washington Department of Fish and Wildlife; managers from the National Oceanic and Atmospheric Administration’s Protected Resources Division West Coast Region, economics consulting companies (“IEc,” 2022; “Earth,” 2022), and local researchers. Common attributes for whale watching tour DCE models include: tour cost, vessel distance whale viewing, number of boats in proximity of the tour, and time spent with whales. To choose which attribute levels to include in the survey scenarios, we relied especially on expected experience descriptions from the Pacific Whale Watching Association. Table 1 details these attributes and the levels used in our DCE.

Table 1: Discrete choice experiment attributes

Attribute	Levels	Explanation
Type of whale observed	SRKW; transient killer whales; humpback whales	These are the most common types of whales viewed in the Salish Sea area. Most tours in the Salish Sea choose a whale group for viewing based on distance from their port and the number of boats already present rather than focusing on viewing a specific type of whale[2]. Both transient killer whales and humpback whales are present in the region on most peak-season days. We include this attribute to measure consumer WTP for different whale types.

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[2] Grey Whale tours in the region are the exception that specifically view Grey Whales. The majority of tours avoid too many boats with each whale group and optimize distance to choose among what whales to view.

Distance from whales	100 yards; 200 yards; 300 yards	Distance was described as the closest "acceptable" viewing distance from whales to the viewing boat and was visually illustrated (see Figure 2). To accurately measure WTP, we allow illegal combinations of whale and viewing distance; respondents were assured that they should respond based on their preferences as the questions were hypothetical.
Time spent with whales	20 minutes; 40 minutes; 60 minutes	The amount of time spent viewing whales during an approximately 4-hour tour.
Number of boats in proximity	3 boats; 10 boats; 20 boats	The number of boats in proximity to whales while viewing whales. Respondents were informed that this value may include both recreational and commercial boats. The average number of boats near whales in the Salish Sea from 2010-2019 is 13 ("Soundwatch," 2022).
Company environmental commitment	Whale donation; salmon donation; whale research; no donation or research	Categorical variable with companies labeled as donating an unspecified amount of money to a whale organization, salmon organization, or participating in whale research in an unspecified manner.

Cost	$90; $115; $140; $165	Cost for a 4-hour tour. US-based Pacific Whale Watching Association ticket prices for a 3-5 hour group tour range from $95 to $159 per-person, with an average among companies of $124 as of August 2021. A wide range of costs improves WTP estimate efficiency.

Several common whale watching DCE attributes were not included, including onboard education, size of whale watching vessels, and probability of seeing whales. We did not include these attributes because they are not policy-actionable in this fleet and they increase cognitive burden for respondents (Flynn et al., 2016; Jonker et al., 2018). Most, if not all, tours in the region provide onboard environmental education that varies with the wildlife seen and guest interests[3]. Although vessel size is often a very important factor in an individual's tour selection (Kessler et al., 2014), it exhibits significant heterogeneity in choices[4] not relevant for policy management that would dominate DCE selection, such as: getting seasick, not enjoying crowds on vacation, or being afraid of the water. Additionally, due to the large capital costs of new boats, this attribute is not likely to influence tour operators. The probability of seeing a whale was not included because historically over 90% of boat tours in the Salish Sea observe at least one whale ("Whale," 2022a), and almost all tours view wildlife of some type. Additionally, many tours offer some sort of "guarantee" that allows guests to return for free if they do not observe whales.

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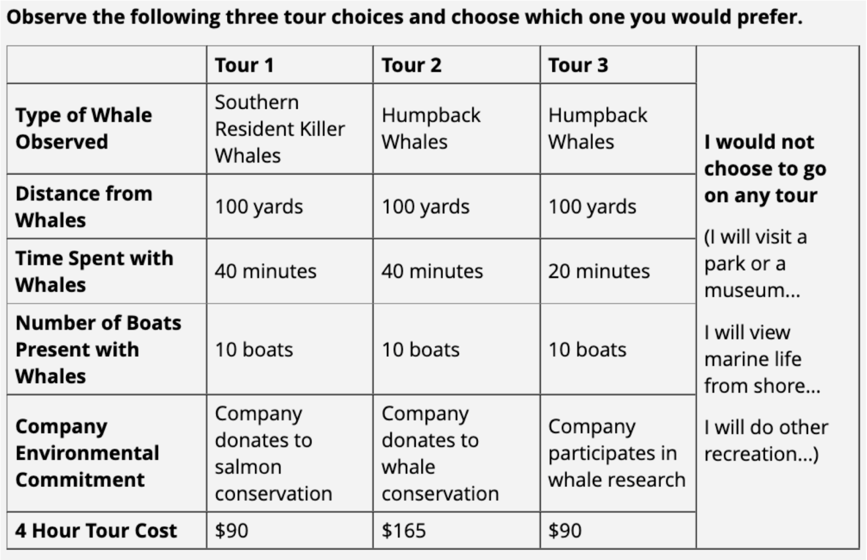
[3] Personal communication with Jeff Friedman and Erin Gless, the U.S. Vice President and Executive Director of the Pacific Whale Watching Association, respectively.

[4] 63% of our sample preferred boats with less than 20 passengers, 34% preferred 20-50 passengers, and 3% preferred larger boats with 50+ passengers

The US Marine Mammal Protection Act specifies that boats stay at least 100 yards from all whales. Additional regulations apply in Washington. The following photos show whales 100, 200, and 300 yards away.

Figure 2: Distance and whale examples included in the survey.



Observe the following three tour choices and choose which one you would prefer.

	Tour 1	**Tour 2**	**Tour 3**	
Type of Whale Observed	Southern Resident Killer Whales	Humpback Whales	Humpback Whales	**I would not choose to go on any tour** (I will visit a park or a museum... I will view marine life from shore... I will do other recreation...)
Distance from Whales	100 yards	100 yards	100 yards	
Time Spent with Whales	40 minutes	40 minutes	20 minutes	
Number of Boats Present with Whales	10 boats	10 boats	10 boats	
Company Environmental Commitment	Company donates to salmon conservation	Company donates to whale conservation	Company participates in whale research	
4 Hour Tour Cost	$90	$165	$90	

Figure 3: Example of a survey question.

3.2.2 Design of the Discrete Choice Experiment

DCE are analyzed with random utility models, which are frequently used in the marketing, tourism, and health literature wherever individuals choose among distinct alternatives, such as to take a whale watching tour or not take a tour. Random utility models rely on three assumptions: that the choices are discrete events, that the attraction of each option varies by individuals as a random variable, and that individuals choose the option that maximizes their utility (Manski, 1977). Researchers can estimate a coefficient for each independent variable by estimating the probability that an individual chooses an alternative in each scenario.

We used the Ngene software (ChoiceMetrics, 2018) for the DCE design. We selected a WTP-error minimizing Bayesian efficient design to optimize for WTP and also to avoid scenarios where one alternative was clearly preferred to another. WTP-error minimizing designs, another name for C-efficient designs, minimize the variance of the ratio between a cost parameter and other attribute parameters based on D-efficiency (Scarpa and Rose, 2008). In general, efficient designs aim to minimize the standard errors of the model and perform better than orthogonal designs when different attribute levels are present (Zwerina et al., 1996). Bayesian parameters may be used when the prior parameters for the design are not known, and therefore the researcher may not want to fix the prior parameters for utility estimates of each attribute level. To obtain Bayesian parameters, we first created an orthogonal design with 15 scenarios that we tested on a convenience sample. Estimated pilot test parameters were used to create random normal distributions for the utility parameters used in the Bayesian DCE design (ChoiceMetrics, 2018). The Bayesian design creates a list of tour scenarios paired as questions for respondents to answer that have similar utility to measure WTP for attributes as efficiently as possible.

DCE questions are known to be cognitively taxing for respondents (Flynn et al., 2016; Jonker et al., 2018). To reduce the complexity of questions, we held at least 2/6 attributes constant at one value per scenario. Since cost always varied between questions, ⅖ of the other attributes were held constant. This practice both reduces the difficulty of comparing six attributes to each other and helps reduce "rule of thumb" issues where respondents make decisions solely based on one attribute to simplify the problem (Scott, 2002). A list of 1,632 candidate attribute profiles included 16 sets of three scenarios for each pair of attributes held constant. Levels of non-fixed attributes were randomized. The modified Fedorov algorithm then picked 30 sets of three scenarios for the survey, blocking them into six groups of five DCE questions (Cook and Nachtrheim, 1980). We manually re-blocked some groups to ensure each group saw variation in all attributes.

We included an opt-out option in the survey. While including an opt-out can reduce the efficiency of estimation, consumer choices almost always include an opt-out (Lancsar and Louviere, 2008). For instance, people vacationing in Seattle can do many things besides commercial whale watching and visitors to the San Juan Islands can view marine life from the shore at parks or participate in a different activity in the region. Our DCE questions specifically mentioned potential opt-out activities like visiting a park, museum, watching marine life from shore, or engaging in other recreational activities, as seen in Figure 3.

3.2.3 Analysis

Random utility models can estimate a marginal utility coefficient for each independent variable. The cost coefficient - the marginal utility of spent income - is expected to be negative (Adamowicz et al., 1994). Previous work suggests the number of boats in proximity and viewing distance coefficients will be negative while time spent with whales will be positive (Andersen and Miller, 2006; Kessler et al., 2014; Torres-Matovelle and Molina-Molina, 2019). We expected the time spent with whales coefficient to be positive. The expected signs for the dummy variables for the type of whale viewed and company environmental commitment categorical attributes are less clear. Coefficients for SRKW and transient killer whales were compared to the omitted humpback whales, and individuals may have many reasons for preferring one whale over the other, including: a desire to see rare animals, or to avoid disturbing endangered animals.

Coefficient estimates were calculated with the following equation:

$$U = ASC + \beta_{cost}\,(\beta_{SRKW} * SRKW + \beta_{Transient} * Transient + \beta_{Distance} * Distance$$
$$+\beta_{Boats} * Boats + \beta_{Time} * Time + \beta_{Whale\ Donation} * Whale\ donation$$
$$+\beta_{Salmon\ Donation} * Salmon\ donation + \beta_{Whale\ Research} * Whale\ research +$$
$$Cost)$$

where the alternative specific coefficient (ASC) for tour utility is fixed at zero and an opt-out ASC is estimated. The β_k estimate the marginal utility coefficients. For ease of calculation, estimation was done directly in the WTP space, though otherwise WTP estimates could be obtained for each attribute k by: $WTP_k = -\frac{\beta_k}{\beta_{cost}}$.

We conducted the DCE analysis in R using the Apollo package (Bunch et al., 1993; Hess and Palma, 2019) with a multinomial logit model. In addition to a basic model that estimated the nine coefficients, we estimated a model with only dummy variables for all attributes to detect any nonlinearity in the distance, number of boats, and time attributes. The non-linear effects model omits the middle level of each attribute: 200 yards, 10 boats, and 40 minutes.

3.3 Latent Class Model

To explore heterogeneity of attribute preferences within the sample, we use an unrestricted latent class model for non-cost attributes. Latent class models assume that the population is composed of several discrete classes of people with different latent preferences (Greene and Hensher, 2003). The probability that an individual i belongs to class j is $\pi_{i,j}$, with $0 \leq \pi_{i,j} \leq 1$ and $\Sigma_j \pi_{i,j} = 1$. Having multiple classes reveals heterogeneity in preferences, such as distance or type of whale viewed, that may have positive or negative coefficients depending upon the class. Additionally, latent class models can identify groupings of individuals with multiple higher or lower WTP coefficients (Semeniuk et al., 2009) who may be differentially affected by policy changes. All non-cost β_k and the ASC coefficients were estimated separately for each class. The ASC is of particular interest to identify WTP for whale watching tours and can identify classes that may not choose a whale watching tour as tour conditions change.

Unlike all other coefficients, the cost coefficient was not separated by class. While cost is necessary to obtain WTP estimates for other attributes, cost reveals significant heterogeneity due to individual budget constraints and valuation of whale watching that is not expected to change with commercial whale watching rule changes. Another source of cost heterogeneity is that much of our sample must travel, often fly, to get to the Salish Sea area to whale watch. For those tourists, the cost of a whale watching trip is a very low portion of their overall trip cost once travel costs are included. Therefore, we chose to estimate one cost coefficient so that our latent class analysis focuses on non-cost sources of heterogeneity. We will discuss the robustness of our policy results in the context of cost non-attendance as a robustness check and we also include a latent class model that estimates separate cost coefficients for all classes in appendix table A3.

3.4 Attribute Non-Attendance

As a robustness check and to investigate ANA, where respondents ignore one or more attributes while responding to the survey, in our sample, we estimated an equality-constrained latent class (ECLC) model. ECLC models include a different latent class for each non-attendance pattern and estimate one coefficient for each attribute based only on the classes that attend to that attribute, hence the name “equality-constrained” (Lew and Whitehead, 2020).

A full ANA model of k attributes would include 2^k classes, and in most cases would be overspecified, so researchers typically estimate models with a subset of classes. Many different methods of choosing non-attendance classes have been proposed, including choosing only one attribute such as cost (Lew and Whitehead, 2020). We estimated non-attendance to each attribute (including cost), attendance to all attributes, and non-attendance to all attributes for a total of eight classes. ANA Model 1 is a true ECLC model, and estimates one ASC for all classes. ANA Model 2 is a modified ECLC model that estimates a separate ASC for each class, while equality constraining all other coefficients between classes, similar to Glenk et al. (2015).

3.5 Policy Analysis

We simulate the effects of various possible commercial whale watching attribute rule changes using our latent class model estimates. Rule changes can affect attributes such as the viewing distance, the number of boats in proximity while viewing, or potentially the amount of time spent with whales. The type of whale viewed attribute can also be impacted by viewing limitations or moratoriums, such as restricting SRKW viewing. We estimated TWTP for various combinations of tour attributes to estimate the percent of possible tourists that would be willing to pay at least $100 for a whale watching tour, thereby obtaining estimates for changes in demand for whale watching tours as tour attributes change.

We obtained TWTP estimates by adding relevant attribute level coefficients to the negative opt-out coefficient, as the negative of the opt-out is the intercept for a base whale watching tour. We obtained standard error estimates for TWTP using the delta method (Oehlert, 1992). We then compared each classes’ TWTP and the total quantity demanded of tours with various attribute combinations to a “base” tour where transient killer whales were viewed from 200 yards away, which is likely the most common tour experience in the Salish Sea. We calculated a z-score for each tour compared to the base tour to compare the estimates (Clogg et al., 1995):

$$z = \frac{TWTP_l - TWTP_{base}}{\sqrt{s.e.(TWTP_l)^2 + s.e.(TWTP_{base})^2}}$$

To estimate the percent of tourists that would be willing to pay for a whale watching tour for each tour specification, we drew 10,000 TWTP estimates for each tour type. We split up the 10,000 draws deterministically by the percentage of our sample in each class. TWTP draws used a normal distribution with the classes’ TWTP as the mean and the standard error of the TWTP for the standard deviation. We calculated the percent of tourists that would be willing to pay at least $100, a tour cost on the low-range that allows for a small amount to be spent on travel costs. We calculated the percent change in the number of tourists compared to the base tour number of tourists using the following formula:

$$\%\,change = \frac{\#\,tourists_{tour\ l} - \#\,tourists_{base\ tour}}{\#\,tourists_{base\ tour}}$$

We specified tour combinations using one type of whale, viewing distance, number of boats in proximity, and time spent with whales. Respondents answered DCE questions with some uncertainty about the type of whale they would observe on any tour; we use this level of uncertainty to measure TWTP for tours with a specific whale that tourists may expect or hope to see. Our base tour specified that transient killer whales were viewed from 200 yards away, the permitted viewing distance in the state of Washington, with 10 boats in proximity (the average number of boats present), for 40 minutes. Tour combinations included distance changes, amount of time changes, and changes in the number of boats present. We also changed the type of whale from transient killer whales to SRKW or humpback whales.

4. Results

4.1 Respondent Characteristics

We report our full respondent characteristics in Appendix Table A2. Our sample aligns well with previous samples of Salish Sea whale watchers on education and age, as seen in Figure 1. Our high proportion of female respondents can be attributed to higher rates of women whale watching in the Salish Sea (Barnes-Crouse, 2019), women in general doing more research for travel plans (Toh et al., 2011), and Facebook's advertising algorithm. Respondent income was higher than the national median, as expected based on the majority college-educated sample. The majority of our respondents, 88%, were white; as previous studies on whale watchers do not typically report race or ethnicity, we cannot compare this demographic. While these demographics are not consistent with national averages, we aimed our sample at potential Salish Sea whale watchers, not the general population, to understand potential tourist preferences for Salish Sea whale watching.

Whale watching tour customers come to the Salish Sea from all over the U.S., Canada, and the world (Andersen and Miller, 2006). Similar to Andersen and Miller (2006), more than 50% of our respondents reported a home zip code more than 1,000 miles from the Seattle area, while 18% of respondents live within 100-1,000 miles of Seattle. Furthermore, 29% of our sample lives within 100 miles of the Salish Sea, including Seattle. The Salish Sea remaining one of the best locations to watch killer whales in the US (Giles and Koski, 2012) explains the high proportion of cross-country tourists. Finally, we found that 80% of our sample had previously been whale watching, and 42% had done so in the Salish Sea.

4.2 Discrete Choice Experiment

Table 2 presents the results for representative consumer models without heterogeneity. All coefficients other than cost are WTP estimates, and the cost estimates remain in utils to allow comparisons between the models. The base model includes the WTP for each attribute and linear estimates for distance, number of boats, and time. Linear coefficients are measured in yards, number of boats, and minutes with level units being 100 yards, 10 boats, and 20 minutes. The non-linear effects model directly estimates WTP for each level of distance, number of boats, and time spent with whales. We interpret the non-linear effects model as we find evidence of non-linear WTP for some attributes.

Consistent with intuition, the representative consumer prefers viewing whales from closer by, for longer times, and with smaller crowds; additionally, they value the distinctive experience of viewing killer whales to the humpbacks they can see elsewhere. Overall sample estimates for a reduction in the viewing distance and the number of boats in proximity are both large and positive: \$58 ($p<0.001$) and \$56 ($p<0.001$), respectively. While marginal WTP estimates for time spent with whales are positive for more time, as expected, we find evidence of nonlinearity as tourists are willing to pay over \$70 ($p<0.001$) to increase their time spent with whales from 20 to 40 minutes, yet they are only willing to pay around \$10 ($p<0.05$) to increase from 40 to 60 minutes. Killer whales of either type are preferred to the omitted humpback whales, with overall WTP to view SRKW over \$50 ($p<0.001$) and overall WTP to view transient killer whales over

\$30 ($p<0.001$)[5]. Company environmental commitment WTP estimates are smaller and have a limited effect on overall WTP, so we do not focus on this attribute.

The opt-out coefficient is large and negative, indicating that respondents are willing to pay a large amount, over \$200 ($p<0.001$) in either homogeneous model, to go whale watching on a base tour, the negative of the opt-out. While the opt-out coefficient is large in magnitude, some respondents chose to opt-out many times. A small percentage of our sample, 3.6%, opted-out of all tour scenarios due to cost (N=6), stated dislike of commercial whale watching (N=13), stated dislike of Salish Sea area whale watching or other more specific impact concerns (N=21), or other reasons including sea sickness or commonly viewing whales from the shore (N=14). Of the "takers" or respondents that choose at least one tour scenario other than opting-out, 9.1% of selections were opt-outs. Almost 73% of respondents did not opt-out at all, and 18% of respondents opted-out only one or two times.

Table 2: Discrete choice experiment results in the WTP space

Multinomial Logit Estimates (robust standard errors)

		Base Model		Non-Linear Effects Model	ANA Model 1	ANA Model 2
Whale	SRKW	53.68*** (7.29)		51.53*** (7.2)	45.82*** (9.04)	51.44*** (6.75)
	Transient KW	32.77*** (5.84)		37.69*** (5.88)	33.40*** (6.86)	36.68*** (5.22)
Distance from boat (yards)		-0.58*** (0.05)	100 yards	58.25*** (6.86)	56.44*** (13.89)	78.00*** (12.98)

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[5] The SRKW and transient killer whale coefficients are statistically different ($p<0.05$). Tested using a likelihood ratio test with the restricted model estimating one killer whale coefficient.

			300 yards	-54.84*** (6.31)	-63.88*** (17.62)		-86.37*** (15.87)
Boats in proximity		-6.41*** (0.47)	3 boats	56.44*** (6)	40.92*** (11.22)		63.07*** (6.66)
			20 boats	-59.69*** (6.12)	-66.75*** (14)		-77.86*** (7.68)
Time (minutes)		2.04*** (0.18)	20 minutes	-71.81*** (6.43)	-58.99*** (10.25)		-65.03*** (6.55)
			60 minutes	10.63* (4.77)	18.09** (5.92)		18.38*** (4.07)
Company Environmental Commitment	Whale Donation	9.49 (5.53)		9.83 (5.48)	7.22* (3.53)		9.14* (3.93)
	Salmon Donation	25.79*** (6.41)		28.86*** (6.43)	10.55* (4.33)		12.97** (4.89)
	Whale Research	12.61* (6.1)		10.35 (6.14)	15.10** (4.88)		17.36*** (4.75)
Cost		-0.0092*** (0.0005)		-0.0093*** (0.0005)	-0.022*** (0.0026)		-0.015*** (0.0011)
Opt-Out		-306.9*** (16.54)		-221.1*** (11.79)	-225.8*** (32.11)	Opt-Out a	203.1 (884.7)
						Opt-Out b	-71.03*** (11.29)
						Opt-Out c	-256.2*** (20.78)
						Opt-Out d	-322*** (28.31)

				Opt-Out e	-115.4*** (34.98)
				Opt-Out f	-973.5*** (188.4)
				Opt-Out g	-1110*** (105.2)
				Opt-Out h	319.3*** (52.8)
Number of Respondents	1442	1442	1442		1442
Rho-Squared	0.102	0.105	0.153		0.1904
BIC	18037	18005	17109		16423
Log-Likelihood	-8974	-8945	-8466		-8092

Note: ***, **, and * indicate p-value <0.001, <0.01, and <0.05 respectively.
Standard errors are clustered for each individual and computed using the sandwich estimator.
Base Model units for distance, number of boats in proximity, and time spent with whales are: 1 foot farther from the whales, 1 more boat in proximity of whales, and 1 more minute spent with whales, respectively.
All coefficients other than cost are presented directly in terms of WTP. The cost coefficient is measured in utils.
Classes for both ANA Model 1 and 2: class a, full attendance; class b, whale non-attendance; class c, distance non-attendance; class d, boat non-attendance; class e, time non-attendance; class f, environmental commitment non-attendance; class g, cost non-attendance; class h, full non-attendance.

4.3 Latent Class Analysis

To understand preference heterogeneity, we conducted a latent class analysis (results in Table 3). Grouping individuals into classes yields easier interpretation of correlated marginal utilities and allows us to estimate classes that may choose to opt-out under certain attribute changes (Semeniuk et al., 2009). We estimate a four-class model using a common cost parameter for all classes and separate coefficients for all other estimates, including the opt-out intercept. We chose the four-class model because although the three-class model performed nearly as well as a four-class model (BIC = 16649), it segmented more respondents into the largest class, obscuring some class results. A five-class model did not converge even with an initial value starting search. We use nonlinear coefficients in our latent class model as we find evidence of nonlinear preferences for some attributes and for ease of interpretation.

Table 3: Latent class analysis results in the WTP space

		Multinomial logit estimates (robust standard errors)			
		Group 1 “Enthusiastic whale watchers”	Group 2 “Nature tourists”	Group 3 “Value-minded whale watchers”	Group 4 “Non-whale watchers”
Whale	SRKW	83.6***	61.89*	-12.24	-24.35
		(16.42)	(31.49)	(-27.45)	(38.03)
	Transient KW	50.72***	78.48***	-9.36	-18.69
		(13.03)	(18.99)	(26.21)	(33.49)
Distance from boat	100 yards	86.49***	-35.64	165.9***	-15.59
		(20.44)	(25.53)	(25.71)	(39.01)
	300 yards	-110.62***	52.27*	-208.8***	-61.24
		(19.78)	(23.04)	(-39.38)	(56.84)
Boats in proximity	3 boats	18.66	135.27***	30.15	162.28***
		(10.43)	(31.68)	(26.82)	(38.91)
	20 boats	-70.64***	-104.81***	-3.81	-184.34***
		(10.2)	(21.98)	(23.48)	(41.88)
Tour time	20 minutes	-94.81***	-83.99***	-70.59**	-59.49
		(11.78)	(20.45)	(24.56)	(45.7)
	60 minutes	25.8**	-7.67	2.44	11.6
		(8.78)	(17.01)	(19.34)	(35.7)
Company environmental commitment	Whale donation	25.88**	-47.84	10.14	37.72
		(9.21)	(27.04)	(24.65)	(45.63)
	Salmon donation	20.03	-1.94	62.35*	19.22
		(10.65)	(19.55)	(27.1)	(44.66)
	Whale research	28.36*	-2.53	-21.38	24.22
		(13.2)	(24.3)	(28.3)	(37.08)
Cost			-0.011***		
			(0.00057)		

Opt-out	-521.8*** (57.94)	-276.1*** (42.54)	-112.7** (35.77)	100.8** (39.09)
Number of respondents	853	330	145	114
Rho-squared	0.1959			
BIC	16536			
Log-likelihood	-11023	-10620	-12191	-20560

Note: ***, **, and * indicate p-value <0.001, <0.01, and <0.05 respectively.
Standard errors are clustered for each individual and computed using the sandwich estimator.
All coefficients other than cost are presented directly in terms of WTP. The cost coefficient is measured in utils.

The largest class, Group 1, includes 56.6% of respondents, and represents "enthusiastic whale watchers." Coefficients are similar to that of the overall model with a positive and significant WTP for SRKW (\$83, $p<0.001$), transient killer whales (\$50, $p<0.001$), and more time (\$94 for 40 minutes instead of 20 minutes, $p<0.001$). Group 1 has lower magnitude WTP estimates for viewing distance and the number of boats in proximity than some other classes and has the most negative and largest WTP for the opt-out, -\$522 ($p<0.001$), indicating that this group is made up of whale watchers. Group 2, 24.6% of the sample, prefers a distinctive Northwest natural wilderness experience, representing the "nature tourists." Group 2 is the only class other than Group 1 with a positive, statistically significant WTP to view SRKW (\$61, $p<0.001$) or transient killer whales (\$78, $p<0.001$) rather than humpback whales. Among Groups 1-3, Group 2 has the largest coefficients for the number of boats in proximity (\$135 for 3 boats instead of 10 boats, $p<0.001$). Also, this is the only class with a positive WTP for a farther viewing distance from the whales (\$52 to view from 300 yards instead of 200 yards, $p<0.05$), likely reflecting concern for whale impacts from viewing. The opt-out coefficient is smaller than for Group 1 but still over \$250 ($p<0.001$).

Groups 3 and 4 have the smallest opt-out coefficients, -\$112 ($p<0.01$) and \$100 ($p<0.01$), respectively. Group 3, 10.8% of the sample, most desires a close-up experience with whales of any type and represents the most "value-minded whale watchers." The coefficient for viewing the whales from 100 yards compared to 200 yards is \$166 ($p<0.001$), while the coefficient for viewing from 200 yards instead of 300 yards is \$209 ($p<0.001$). Group 3 does not have a large or statistically significant WTP to view killer whales as compared to humpback whales, nor does this class have a large WTP for the number of boats in proximity. Group 4, the smallest class at 8.0% of our sample, is composed of people interested in whales but not interested in whale watching as indicated by the positive opt-out coefficient ($p<0.01$). This class, the "non-whale watchers." has large and significant coefficients for only the number of boats in proximity and the opt-out.

4.4 Attribute Non-Attendance

The representative consumer model may oversimplify differences among individuals, biasing coefficients toward zero if different respondents are attending to different subsets of attributes. As a robustness check for respondent ANA, we estimated two ECLC models with 8 latent classes, presented in Table 2. Model 1 does not estimate a separate opt-out for each group, while Model 2 does. As expected, because Model 2 estimates more coefficients, Model 2 attains a better log-likelihood. ANA model coefficients are smaller than the homogenous model estimates when cost non-attendance dominates other attribute non-attendance. ANA Model 1 indicates that the cost coefficient, which more than doubled, dominated the non-attendance effects of most other attribute levels, indicating that most of our sample were in the market for whale watching tours across our range of tour costs. While ANA Model 1 indicates that 27% of our sample did not attend to any attribute, once separate ASC are estimated in ANA Model 2, only 4% of our sample is estimated to not attend to any attribute.

ANA Model 2 indicates that the somewhat larger cost coefficient in the homogeneous models results in a lower estimate for the type of whale and time spent with whales attribute coefficients. The number of boats in proximity and distance attribute coefficients increase compared to our homogenous model results, though do not change in sign or overall interpretation. The opt-out coefficients range from positive $319 ($p<0.001$), indicating that this class is not willing to pay a positive amount to whale watch, to -$1110 ($p<0.001$), suggesting that this class would choose to whale watch under almost all tour conditions[6]. Both of our ANA model estimates are of similar size and magnitude to our non-linear homogenous model estimates.

4.5 Policy Analysis

To evaluate the welfare and demand effects of specific proposed regulatory changes, we use our latent class model to calculate each classes' TWTP for trips with alternative attributes. We report the estimated percent of our sample that would be willing to pay at least $100 (a typical market price) for each tour specification and the percent change in demand for each tour specification compared to the base tour in Table 4. The base tour, reflecting the regulatory status quo, views transient killer whales from 200 yards away for 40 minutes with 10 boats in proximity. Tours 1 through 11 reflect tours that vary from the base tour by viewing a different type of whale, viewing from 100 or 300 yards, tours with a different number of boats in

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[6] While the very large opt-out coefficient for latent Class g, the class with a -$1110 opt-out which does not-attend to cost, may seem unreasonably high, keep in mind that much of our sample is made up of tourists traveling and staying in the Puget Sound area overnight, for whom the ticket price may be a small overall portion of their trip cost. For this latent group specifically, only 16% of the respondents predicted to be in this latent group would take a day trip to the whale watching location, as compared to 23% of our overall sample.

proximity, or tours that view whales for a different amount of time. The percent of our sample that would be willing to pay at least $100 to go on each tour are compared to the base tour in each case. The TWTP estimates and standard errors are reported in Table A4.

Our results indicate that for all tour scenarios, over 80% of our sample would be willing to pay at least $100 to go whale watching. Most tours that have a greater than 5% change in the number of respondents willing to pay at least $100 are tours with a different viewing distance than the base tour, the only exception being tour 6, which spends only 20 minutes with whales. Group 3, the class with an opt-out closest to $100, is willing to pay the most for a close-up viewing distance and therefore affects demand the most. We do not see that changes in the type of whale viewed cause large changes in the number of respondents willing to pay at least $100 to go whale watching.

Table 4: Total willingness-to-pay (TWTP) for whale watching tours

	Tour Attributes				TWTP % Change Latent Class ($)	
Tour	Whale Viewed	Viewing Distance	Number of Boats	Time with Whales	% sample willing to pay >$100	% change in demand from base tour
Base	Transient KW	200 yards	10	40 minutes	87%	-
1	Transient KW	100 yards	10	40 minutes	92%	6%
2	Transient KW	300 yards	10	40 minutes	81%	-7%

3	Transient KW	200 yards	3	40 minutes	92%	5%
4	Transient KW	200 yards	20	40 minutes	87%	-1%
5	Transient KW	200 yards	10	60 minutes	88%	1%
6	Transient KW	200 yards	10	20 minutes	82%	-6%
7	SRKW	300 yards	10	40 minutes	81%	-7%
8	SRKW	300 yards	3	40 minutes	81%	-7%
9	Humpback	100 yards	10	40 minutes	92%	6%
10	Humpback	200 yards	10	40 minutes	88%	1%
11	Humpback	300 yards	10	40 minutes	81%	-7%

Note: The TWTP percent change represents the percentage of respondents willing to pay at least $100 for a whale watching tour as specified, based on TWTP calculations.

5. Discussion

Balancing both strong coastal economies that rely on natural resources and sustainable wildlife tourism are key management concerns. While some conservation measures, such as increasing whale viewing distances or reducing whale observability (Lee et al. 2019), reduce tour satisfaction for some tourists, other changes increase tour satisfaction. Our survey and results add to the literature on managing tours that view wildlife, especially in multispecies contexts with endangered species.

Previous researchers have found that whale watching tourists value seeing whales (Andersen and Miller, 2006) and a close viewing distance (Kessler et al., 2014) more than any other tour attributes. According to our results, Salish Sea tourists are willing to pay the market rate for a common whale watching tour experience of viewing transient killer whales from a 200 yard viewing distance. Our results indicate that among our attributes, the viewing distance affects demand for whale watching tours the most. While most of our sample (87%) is willing to pay at least $100 to view transient killer whales from 200 yards away, only 81% is willing to pay $100 if the viewing distance is 300 yards. Conversely, if viewing of non-endangered whales such as transient killer whales is allowed from 100 yards away, 92% of our sample is willing to pay at least $100 for a tour. The marginal consumers swayed by changes in the viewing distance are the value-minded whale watchers, who have an opt-out coefficient near to $100, making them the group most likely to have their ticket purchasing behavior affected by changes in tour attributes.

Our other attributes, while having large marginal WTP estimates for some groups, do not largely affect TWTP near the ticket price of $100. Consistent with Torres Matovelle and Molina-Molina (2019), our results indicate that the number of boats in proximity is an important attribute to many tourists. However, our estimates indicate that groups with a very large TWTP for the number of boats in proximity have either a very large TWTP or a very low TWTP and are therefore unlikely to impact demand for whale watching. While we do find evidence that Salish Sea whale watchers are willing to pay more to view distinctive orcas, and SRKW in particular, than humpback whales, most respondents are willing to pay to go whale watching for any of the three types of whales we tested. The time spent with whales can have a large impact on the percentage of our sample willing to pay $100 to go whale watching, specifically when only 20 minutes instead of 40 minutes is spent with whales. Our data suggests that companies and managers provide at least 30-40 minutes of viewing to provide an experience tourists find fulfilling.

Salish Sea whale watching rules have been subject to change and include different viewing distances for different types of whales. A report commissioned by the Washington Department of Fish and Wildlife indicated that a 14-27% decrease in ridership within the whale watching industry would threaten industry viability (Kassakian, 2020). We do not find evidence that any of our tour specifications would result in changes in ridership that come near this range, as we found a maximum ridership change of 7% when the viewing distance is 300 yards to view humpback whales. After the conclusion of our survey, Washington passed legislation limiting viewing of SRKW to 1,000 yards for nearly all boaters in Washington, an effective moratorium ("Protecting," 2023). While we did not measure WTP for an effective moratorium on viewing only one type of whale, our results indicate that tourists are willing to pay to view any of our three types of whales, so we do not expect this moratorium to substantially change tourist TWTP for whale watching. We expect that rule changes limiting the number of boats in proximity to whales and rule changes that increase viewing opportunities or lower viewing distances for non-endangered whales will increase demand for whale watching tours. Similar to Kessler et al. (2014), we also found evidence that some tourists (25% in our sample) actually prefer to view whales from farther away, a potential specialization for ecotourism companies. Additional education on marine issues and the impact of whale watching on whales could influence tourist acceptance of eco-tour restrictions, as previous researchers have found that much of the public is aware of and concerned about marine issues, but uninformed about specific actions they can take to protect marine wildlife (Gelcich et al., 2014; Easman et al., 2018).

Managers face many tradeoffs when determining acceptable levels of marine policies for wildlife tours, such as: protecting wildlife and ecosystems, not threatening local coastal economies, and acquiring local support. While our results are specific to Salish Sea whale watching, several of our findings suggest broader themes. Similar to Booth et al. (2011), who found that bird tourists have a low marginal value for viewing rare and endangered birds compared to less rare birds, we found that in a multispecies context, tourists are willing to pay to view non-endangered whales. Managers can, therefore, focus regulations on protecting endangered species, while allowing or expanding viewing of non-endangered species, to protect tourism industries. Our results also suggest that researchers and managers should consider specific sub-populations of tourists when designing wildlife tour regulations. Similar to Semeniuk et al. (2009), we did identify groups that would be willing to pay to view whales from farther away, or may only be willing to pay for tours that guarantee they won't view endangered species. By considering groups of tourists that have a TWTP near average ticket prices, managers can analyze how specific tour attribute changes are likely to impact demand for tours.

Public support for wildlife regulations can be impacted by more than actual tour attribute changes. Bennett (2016) found that even for environmental policies, public perceptions of policies are more responsible for support or non-support than objective evidence. We did not directly consider public perceptions of rule changes or public interpretations about how rule changes would affect actual tour attributes (for example, a tourist understanding a viewing moratorium on SRKW as a viewing moratorium on whale watching in general in the Salish Sea). As approximately 50% of Salish Sea whale watchers travel over 1,000 miles to the area, ocean knowledge and perceptions of residents by geographical area is also important to consider. Steel et al. (2005) did not find evidence that public knowledge of oceans is statistically different between residents of coastal states and non-coastal states, indicating that broader support of policies beyond local, coastal, residents, may be important for marine viewing regulations.

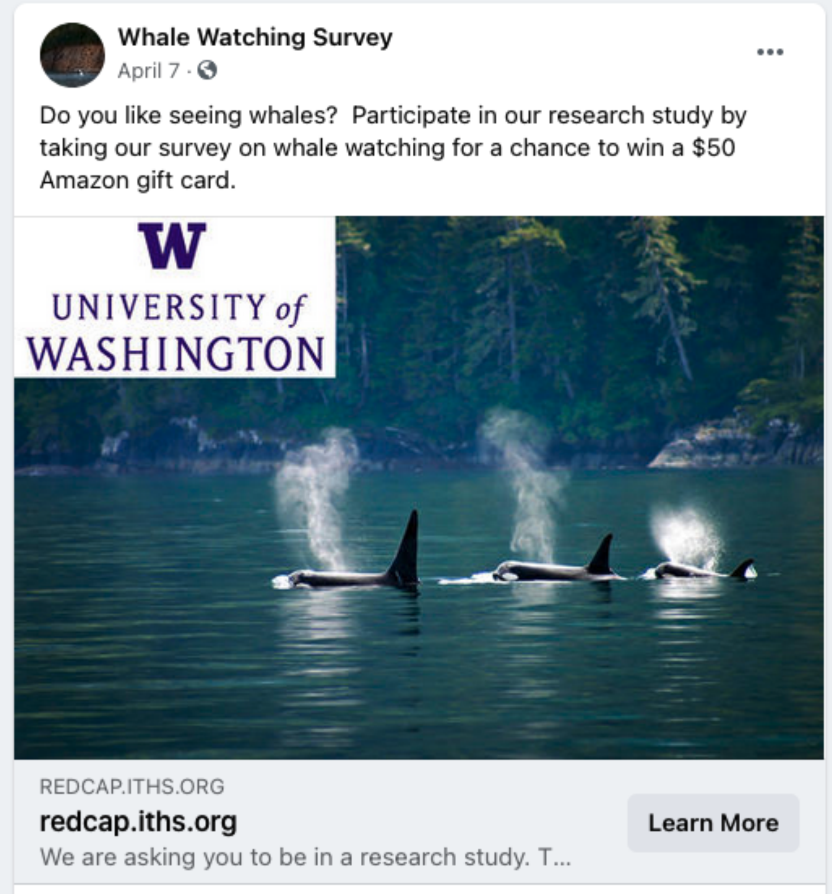
Our survey and results are focused on Salish Sea tourists from a national United States sample of whale watchers. Our sample is representative of Salish Sea whale watchers on age distribution, education, and distance traveled to the Salish Sea, based on previous surveys. Our sample gender is not representative of Salish Sea whale watchers, and we suggest that researchers using social media advertising pay careful attention to gender when distributing advertisements. We additionally suggest that researchers include non-binary and other gender options when designing and reporting surveys, along with race and ethnicity statistics. In addition to gender bias, social media surveys may only be accessible to more affluent populations, something that may be of larger concern for less educated populations.

We carefully considered the potential impacts of the COVID-19 pandemic on respondent answers throughout the survey. Since we collected responses from April to June 2021, many individuals were either not traveling or just considering traveling again. We reminded respondents at the beginning of the survey, and throughout, that the survey was not about COVID-19 effects, and that they should consider "normal" times either before the pandemic or in the future once they recreated normally again.

6. Conclusion

We estimated WTP for various whale watching tour attributes, grouped tourists based on measured preferences for whale watching, and estimated demand changes based on attribute changes. While we do not find that the type of whale viewed is likely to affect ridership in the Salish Sea, maintaining reasonable value for tourists seems to require spending at least 30-40 minutes with whales, and in reasonable proximity. Regulation changes are more likely to impact the viewing distance and the number of boats in proximity; we find evidence that the viewing distance is an attribute that can impact ridership in a large way. Future research may focus on not just how changes in tour attributes affect demand for whale watching, but also if simply learning about changes in rules could impact demand for whale watching. Possible methods include a larger DCE that provides different information treatments to respondents before the DCE questions. While much attention is currently given to SRKW, it would be useful to investigate if discussing other whales or even publicizing their location increases demand or reduces vessels near the SRKW. Other areas of interest include private recreational vessel management and the relationship between recreational vessels and commercial vessels, endangered species management and existence value, and tourist environmental behavioral change after eco-tours.

Appendix



Whale Watching Survey
April 7 ·

Do you like seeing whales? Participate in our research study by taking our survey on whale watching for a chance to win a $50 Amazon gift card.

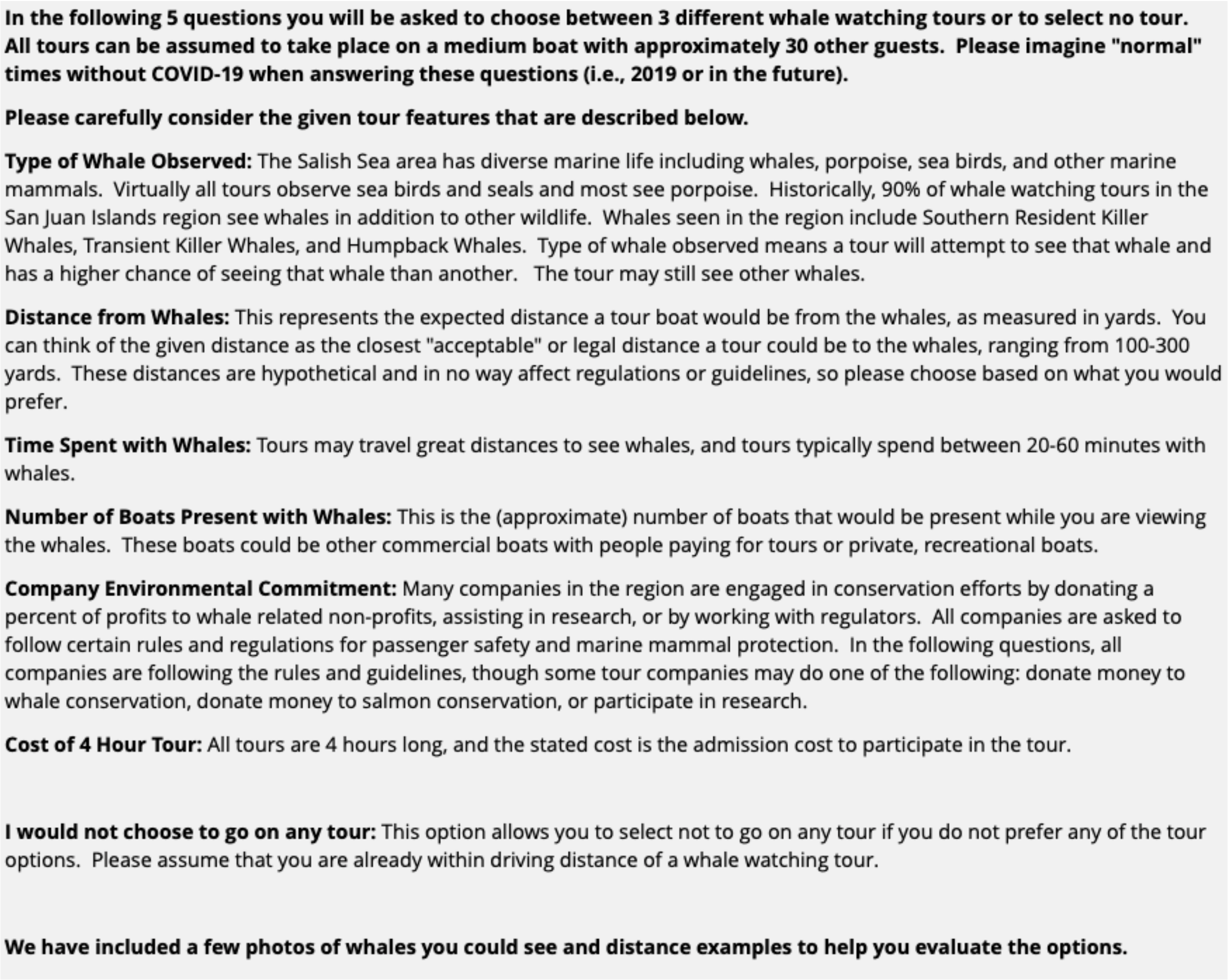
REDCAP.ITHS.ORG
redcap.iths.org
We are asking you to be in a research study. T...

Figure A1: Example Social Media Ad

Table A1: Elimination Checks

Check	Eliminated criteria	Number eliminated
Question: "How did you find out about this survey?"	"Social media post from a friend"	49
Question: "How did you find out about this survey?"	"Emailed/Texted link from a friend"	37
IP address collection	Repeated IP addresses	4

Question that only bots answer	Any answer	0



In the following 5 questions you will be asked to choose between 3 different whale watching tours or to select no tour. All tours can be assumed to take place on a medium boat with approximately 30 other guests. Please imagine "normal" times without COVID-19 when answering these questions (i.e., 2019 or in the future).

Please carefully consider the given tour features that are described below.

Type of Whale Observed: The Salish Sea area has diverse marine life including whales, porpoise, sea birds, and other marine mammals. Virtually all tours observe sea birds and seals and most see porpoise. Historically, 90% of whale watching tours in the San Juan Islands region see whales in addition to other wildlife. Whales seen in the region include Southern Resident Killer Whales, Transient Killer Whales, and Humpback Whales. Type of whale observed means a tour will attempt to see that whale and has a higher chance of seeing that whale than another. The tour may still see other whales.

Distance from Whales: This represents the expected distance a tour boat would be from the whales, as measured in yards. You can think of the given distance as the closest "acceptable" or legal distance a tour could be to the whales, ranging from 100-300 yards. These distances are hypothetical and in no way affect regulations or guidelines, so please choose based on what you would prefer.

Time Spent with Whales: Tours may travel great distances to see whales, and tours typically spend between 20-60 minutes with whales.

Number of Boats Present with Whales: This is the (approximate) number of boats that would be present while you are viewing the whales. These boats could be other commercial boats with people paying for tours or private, recreational boats.

Company Environmental Commitment: Many companies in the region are engaged in conservation efforts by donating a percent of profits to whale related non-profits, assisting in research, or by working with regulators. All companies are asked to follow certain rules and regulations for passenger safety and marine mammal protection. In the following questions, all companies are following the rules and guidelines, though some tour companies may do one of the following: donate money to whale conservation, donate money to salmon conservation, or participate in research.

Cost of 4 Hour Tour: All tours are 4 hours long, and the stated cost is the admission cost to participate in the tour.

I would not choose to go on any tour: This option allows you to select not to go on any tour if you do not prefer any of the tour options. Please assume that you are already within driving distance of a whale watching tour.

We have included a few photos of whales you could see and distance examples to help you evaluate the options.

Figure A2: Pre-DCE Survey Information

Table A2: Respondent characteristics

Individual Demographics	N	Percent
Gender		
Female	1214	84.2
Male	185	12.8
Nonbinary/Gender-fluid/Other	25	1.7
Missing	18	1.2
Age		

18-24	127	8.8
25-39	463	32.1
40-54	351	24.3
55-69	413	28.6
70+	72	5.0
Missing	16	1.1
Race		
Black/African American	16	1.1
Asian	91	6.3
Native American/Pacific Islander/Native Alaskan	33	2.3
White	1251	86.8
Missing	57	4.0
Ethnicity		
Hispanic or Latino	82	5.7
Not Hispanic or Latino	1360	94.3
Missing	51	3.5
Total Household Income		
Less than $39,999	204	14.1
$40,000-$79,999	348	24.1
$80,000-$119,999	298	20.7
$120,000-$159,999	164	11.4
$160,000-$199,999	94	6.5
More than $200,000	98	6.8
Missing	236	16.4

Education		
Some High School	3	0.2
High School Diploma or GED	98	6.8
Trade School	38	2.6
Associate's Degree or 2 years of College	188	13.0
Bachelor's Degree	529	36.7
Master's Degree	434	30.1
PHD/Professional Degree or Higher	131	9.1
Missing	21	1.5

Table A3: Latent class analysis with separate cost estimates

		Multinomial Logit Estimates (robust standard errors)			
		Group 1	Group 2	Group 3	Group 4
Whale	Southern Resident Killer Whales	-26.67 (67.25)	-20.05 (26.22)	54.52*** (12.08)	435.36 (943.9)
	Transient Killer Whales	-29.31 (83.75)	-12.79 (26.86)	32.4* (15.58)	446.49 (928.37)
Distance from boat (yards)	100 yards	28.68 (71.06)	111.63*** (32.33)	65.65*** (19.06)	-108.11 (285.8)
	300 yards	-7.97 (94.36)	-172.35*** (42.25)	-94.76*** (13.72)	113.06 (468.16)
Boats in proximity	3 boats	218.3 (207.41)	26.67 (21.61)	11.26 (10.58)	464.92 (1128.87)

	20 boats	-299.85 (245.93)	-7.24 (20.39)	-42.5*** (10.53)	-549.35 (1342.54)
Time in minutes	20 minutes	-41.8 (61.54)	-64.69** (23.25)	-59.55*** (15.54)	-570.58 (1210.39)
	60 minutes	30.46 (47.99)	1.23 (16.33)	27.81*** (8.44)	-126.84 (335.86)
Company Environmental Commitment	Whale Donation	111.47 (124.13)	14.94 (16.94)	24.35** (7.74)	-193.84 (507.36)
	Salmon Donation	94.48 (113.04)	45.6* (19.97)	12.63 (11.52)	46.23 (124.32)
	Whale Research	51.47 (63.17)	-3.67 (23.5)	29.23*** (8.77)	-90.75 (342.35)
Cost		-0.008 (0.006)	-0.015*** (0.003)	-0.018*** (0.004)	-0.002 (0.004)
Opt-Out		252 (335)	-127*** (31)	-370*** (53)	-1525 (2976)
Class Probability		0.087	0.11	0.418	0.385
Rho-Squared		0.2004			
Log-Likelihood		-20363	-12808	-11891	-10081

Table A4: Total willingness-to-pay estimates and standard errors

	TWTP Estimates (standard errors)			
Tour	Group 1	Group 2	Group 3	Group 4
Base	572.52 (55.51)	354.58 (45.92)	103.34 (30.9)	-119.49 (48.88)

1	659.01	318.94	269.24***	-135.07
	(65.28)	(40.32)	(35.93)	(51.78)
2	461.9	406.85	-105.46***	-180.73
	(50.62)	(39.97)	(49.68)	(50.6)
3	591.19	489.85*	133.49	42.8*
	(55.81)	(41.69)	(37.26)	(61.68)
4	501.88	249.77	99.53	-303.83*
	(53.78)	(54.36)	(35.3)	(63.38)
5	598.32	346.92	105.78	-107.89
	(58.34)	(48.4)	(28.94)	(47.75)
6	477.71	270.59	32.75	-178.98
	(51.88)	(37.47)	(39.11)	(49.4)
7	494.78	390.27	-108.34***	-186.39
	(52.77)	(42.17)	(51.76)	(50.74)
8	513.45	525.54*	-78.19**	-24.1
	(53.78)	(49.16)	(46.15)	(50.16)
9	608.29	240.46	278.6***	-116.39
	(68.57)	(35.93)	(39.97)	(50.58)
10	521.8	276.1	112.7	-100.8
	(57.94)	(42.54)	(35.77)	(39.15)
11	411.18*	328.37	-96.1**	-162.04
	(51.92)	(36.34)	(56.48)	(57.11)

Note: ***, **, and * indicate p-value <0.001, <0.01, and <0.05 respectively for each tour 1-11 as compared to the base tour.

Acknowledgments

The authors thank Leif Anderson, Jeff Friedman and Erin Gless of the Pacific Whale watching Association, Dr. Julie Watson, Tara Galuska, Jen Kassakian, Maura Flight, Dr. Laura Koehn, and Dr. Lynne Barre for their comments and suggestions. This study was funded through Washington Sea Grant project R/HCE-25, "Evaluating the effects of Southern Resident orcas recovery actions and external threats in the marine ecosystem of Puget Sound" awarded to H. Morzaria-Luna. University of Washington Institute of Translational Health Science (ITHS) grant support (UL1 TR002319), KL2 TR002317, and TL1 TR002318 from NCATS/NIH funded REDCap.

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Rent Splitting after Rationalization: Cooperatives and Processor-Allocated Quota

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1. INTRODUCTION

Industry changes, for example season length variation, impact rent sharing between harvesting and processing firms. In fisheries, longer seasons typically both increase overall industry rents by eliminating the "race to fish" and also shift rent from the processing sector to the harvesting sector as ex-vessel prices rise (Matulich et. al., 1996). Estimates of rationalization impacts on the processing sector overall remain uncertain, though changes in processing plant capacity both pre- and post-rationalization are expected (Matulich et. al., 1996; Wilen, 2009). In several fisheries, managers have implemented not fully vertically integrated cooperatives or some form of processor harvesting rights to protect processor market share. Policymakers may be particularly concerned with protecting high- processing plants that provide local jobs and community revenue. We consider how cooperatives and processor-allocated harvesting rights each function and interact to provide the right level of community protection for both the harvesting and processing sectors after quota rationalization.

Fishery managers introduce individual harvesting rights not only to increase overall industry rents, but also to increase harvester safety, allow harvesters to capture resource rents, and increase harvester efficiency (Kearney, 2001). Some fisheries, such as in Iceland and New Zealand, have seen industry consolidation and vertical integration after individual transferable fishing rights (ITQ) rationalization; although desirable for the processing sector, these outcomes may be seen as undesirable for managers (Gunnlaugsson and Valtysson, 2022). Matulich et al. (1996) raised concerns about processing sector outcomes post-rationalization, and Matulich et al. (2001) proposed a processor centered cooperative (PCC) solution while Matulich and Sever (1999) proposed a processor-allocated quota (PAQ) solution. Instituted both as separate policies and combined, these policies transfer unknown amounts of rent from the harvesting back to the processing sector as compared to a standard ITQ. To our knowledge, researchers have not previously characterized potential differential impacts of these policies on processing firms with heterogenous cost functions. It is plausible that high-cost processing plants, of particular concern to fishery managers, may be differentially impacted by these policies as compared to large, industrial, low-cost processing plants.

Our model analyzes harvesting and processing ex-vessel prices and quasi-rents before and after harvesting quota rationalization. We show that if the processing sector is perfectly competitive and processing capital is non-malleable, that processing quasi-rents are very low in the transitional period post-rationalization until processing firm consolidation occurs. We additionally show that both PCC and PAQ, and a combined policy with processor centered cooperatives and processor-allocated quota (PQC) transfer some quasi-rents back to the processing sector. However, these gains in quasi-rents are not experienced equally across the processing sector. Our model shows that PCC alone is better for low-cost processors than high-cost processors, and may even be worse for high-cost processing plants than a standard ITQ. High-cost processor quasi-rents are similar in PAQ to ITQ quasi-rents. Only a combined policy with both cooperatives and processor quota has a larger positive impact on high-cost processor quasi-rents, which may be more important to managers than quasi-rents for low-cost processing plants. Our results show that the profit split within the processing industry does not always mirror overall sector profit sharing, with important differences that can be policy-relevant.

Section two provides background on each management scheme and the fisheries that introduced it. Section three introduces our assumptions and presents our model. Section four discusses our results and implications.

2. BACKGROUND

Early quota rationalization discussions focused on gains within the harvesting sector, such as resource rent and increased safety, yet overlooked the processing sector (Lindner et. al., 1992; Kearney, 2001). Following initial quota rationalization experience, Matulich et. al. (1996) introduced a model of quota rationalization that included the processing sector, providing a framework for our open access to individual harvesting rights model. Matulich et. al. (1996) further showed that for a perfectly competitive processing sector and unless processing capital is perfectly malleable, individual harvest rights necessarily lead to a rent transfer from the harvesting to the processing sector. Wilen (2009) analyzed stranded capital arguments for the processing sector after fisheries rationalization, suggesting that such arguments may be overstated, particularly for large, industrial processing firms that are not likely to be perfectly competitive and will respond to quota rationalization prior to implementation by reducing capital. Amid concerns about processing and harvesting sector outcomes post-rationalization, several variations of PAQ and PCC have been implemented, particularly in United States West Coast and North Pacific fisheries.

Pre-rationalization, the Bering Sea/Aleutian Island crab fishery was one of the most dangerous fisheries (Fina, 2005) in the world, even the topic of a TV show "Deadliest Catch." This Alaskan crab derby total allowable catch (TAC) provided an enormous advantage to the high-cost processing plant on St. Paul Island, a small indigenous community that relies on crab processing to survive (Fina, 2005). Managers desired to rationalize the fishery to increase harvester profits and safety; yet, a standard ITQ system that would have threatened the industry on St. Paul Island faced opposition (Magnuson-Stevens Act, 108th Cong., 2004). An ITQ would give harvesters ample time to travel to Dutch Harbor for crab processing, rendering St. Paul

Island processing obsolete. These concerns led managers to use a two-pie quota system that allocated both harvester and processor quota, thereby guaranteeing St. Paul Island processing market share. Two-pie systems are relatively rare; though Matulich (2008) did not estimate that introducing processor quota hurt harvester profits, the policy remains controversial.

Instead of directly guarateeing processor market share, one-pie systems allocate some harvest quota to processors to gift or lease back to harvesters (Matulich and Sever, 1999). As compensation for potential losses due to underuse of processing capital post-rationalization, Pacific Whiting (*Mercluccius productus)* managers allocated 20% of harvest quota to processors. One issue is that pre-rationalization, sector losses and rents are uncertain, and many estimates of loss can be justified by rent-seeking firms. Additionally, the one-pie quota split is subject to much debate, as it is difficult to justify any particular split. While Matulich and Sever (1999) assume processor quota is leased, evidence from the Pacific Whiting fishery suggests that processors gift quota (lease price of zero) as a way to secure deliveries (Guldin and Anderson, 2019).

The largest U.S. Fishery by volume (Liddel and Yencho, 2022), Alaskan Pollock (*Gadus chalcogrammus)*, was rationalized with a U.S. congress bill. The legislation, the American Fisheries Act, allowed the offshore fleet to vertically integrate, as they already were beginning to, while the nearshore fleet formed cooperatives to receive guaranteed quota shares (Matulich et. al., 2001). Cooperative formation and vertical integration provided monopoly and monopsony concerns that required specific legislation to rationalize this highly industrialized fishery. Specific provisions include a penalty year spent in a derby, competing for a set share of the TAC, for a harvester to switch processing cooperatives. This provision provides a lower bound on payoff for both harvesters and processors, leading processors to gain additional bargaining power as harvester payoff from the derby is expected to be very low. Matulich et. al. (2001) use Nash bargaining to characterize the solution to cooperative ex-vessel prices and harvesting rates, without fully considering harvester outside options to switch cooperatives.

Further fisheries management innovation led to the combination of both a one-pie split in quota and a fishing cooperative, with different provisions than for Alaskan Pollock. This combination policy was instituted in the Pacific Cod (*Gadus macrocephalus)* fishery rationalization in 2023 by the North Pacific Fishery Management Council, allocating 12% of harvest quota to processors and requiring harvesters to join a specific processing cooperative without a penalty year (McCracken et. al., 2021). While the results of this policy remain uncertain, we consider a theoretical model of this combined policy, which to our knowledge has not been done. Additional research on fishing processor-harvester research includes imperfectly competitive processing firms (McEvoy et al., 2009) and vertical integration (Byrne et al., 2019).

3. MODEL

Our model includes harvesters with homogenous cost functions and processors with heterogenous cost functions. For each management system, we will define harvester and processor profit-maximization functions and then present the equilibrium harvesting and processing rates and ex-vessel prices. We then compare the various equilibrium ex-vessel prices and profit for firms, paying special attention to differential impacts for high-cost processors. Table 1 introduces our notation, and our model assumptions are detailed below.

3.1 ASSUMPTIONS AND NOTATION

1. Marginal cost (MC) functions for harvesting and processing firms are increasing and strictly convex in the production range. Average variable cost (AVC) functions are strictly

decreasing and then strictly increasing for harvesters, such that a minimum average variable cost, $\min AVC_h(r_h)$ exists for some rate of harvest $r_h > 0$.

2. Harvesting firm cost functions are homogenous.
3. Processing firm cost functions are heterogenous such that for a processing firm i with a larger marginal processing cost than processing firm j for some processing rate, $\widehat{r_p}$, $MC_i(\widehat{r_p}) > MC_j(\widehat{r_p})$, $\mathrm{argmin}_{\mathrm{r_p}} AVC_i(r_p) < \mathrm{argmin}_{\mathrm{r_p}} AVC_j(r_p)$.
4. Firms are not vertically integrated before or after the introduction of individual fishing rights. Harvesters solely choose harvest rates $r_h = \mathrm{argmin}_{\mathrm{r_h}} AVC_h(r_h)$ in all individual quota models.
5. A sustainable level of total allowable catch (TAC) that does not correspond to overfishing and is at or below the maximum sustainable yield. The TAC remains stable for all management scenarios and is allocated evenly between homogenous harvesters in individual quota games.
6. No crowding effects exist. Additional harvesters or processors do not change the technical efficiency of existing harvesters and processors.
7. Capital is not perfectly transferable between industries and fisheries for either harvesters or processors in the short run or the long run.
8. The wholesale, final product price Z, remains unchanged after the introduction of individual fishing rights and for each management scenario. Wholesalers can access some form of world market.
9. The processing sector is perfectly competitive in both ex-vessel and wholesale markets.

10. Processing fixed costs are much larger than harvester fixed costs, such that: $minATC_p(r_p) \geq 2minATC_h(r_h)$. Generally, there are many harvesters for each large processing plant, such that this would be true.
11. The decrease in processing rates as the season lengthens in individual quota games is such that: $MC_p(r_p^{ITQ}) \leq \frac{1}{2}minATC_p(r_p)$. Very large changes in season length can and often do occur with quota rationalization.
12. There are enough harvesters for each processor such that average variable costs for a processing plant adding one additional harvester post-rationalization are much less than minimum average total processing costs: $AVC_p\left(r_p + \frac{q_m}{T}\right) \leq \frac{1}{4}minATC_p(r_p)$. Most fisheries include many more harvesters than processors, such that even after adding one additional harvester, a processing plan would still have low average variable costs relative to their high fixed-costs.
13. The difference in average variable costs from adding an additional harvester post-rationalization is such that: $\frac{Tr_p}{q_m}\left(AVC_p\left(r_p + \frac{q_m}{T}\right) - AVC_p(r_p)\right) \leq \frac{1}{4}minATC_p(r_p)$ and $\left(AVC_p\left(r_p + \frac{q_m}{T}\right) - AVC_p(r_p)\right) \leq \frac{1}{4}minATC_p(r_p)$. The difference in average variable processing costs from adding one additional harvester multiplied by the number of harvesters delivering to a processing plant is less than or equal to one quarter of a processing plant's minimum average total costs. As the number of harvesters delivering to a processing plant will be greater than one, the difference in average variable processing costs from adding one additional harvester is less than one quarter of the firm minimum average total costs. Many harvesters per processing plant lower the difference in average variable costs compared to high processing firm fixed-costs and average total costs.

14. The share of harvesters at each processor is low enough such that: $\frac{q_m}{T} < \frac{1}{2}\left(minATC_p(r_p) - MC_p(r_p)\right)$. Although there are more harvesters than processors, processing rates must not be greater than one half of the difference between the marginal cost pre-rationalization and the marginal cost post-rationalization. The difference in marginal costs pre- and post-rationalization must be large, which it generally is.

Sections 3.2-3.6 solve for equilibriums in the ex-vessel market, and section 3.7 develops propositions about the relative outcomes.

Table 1: Variable Notation

Notation	Description
Z	Wholesale price for processors.
r_h	Daily harvest rate.
r_p	Daily processing rate.
P	Ex-vessel price paid by processors to harvesters.
T	Time, measured in length of season by days.
m	Individual harvester notation, such that the total number of harvesters equals M.
n	Individual processor notation, such that the total number of processors equals N.
q_m	Individual quota share allocated to harvesters.
s	Quota lease prices in individual quota share games.
w_m	Amount of quota leased in individual quota share games.
g_i	Amount of quota gifted by processor i in processor-allocated quota games.
TAC	Total allowable catch or total quota available.
α	Percentage of the total TAC allocated to the processing sector; $\alpha \in (0,1)$.

3.2 TOTAL ALLOWABLE CATCH (TAC)

Open access fisheries that are restricted by a total allowable catch are characterized by zero profit in both the harvesting and processing sectors (Matulich et. al. 1996). Harvesters and processors compete for product during a short season made up of T^{TAC} days. The binding season length leads harvester and processors to increase their rates of production, r_h^{TAC} and r_p^{TAC}. Harvesters increase production as they “race to fish” the TAC, and processors race to process as harvesters bring hauls in over the short season.

Harvesters

Harvesters maximize their profit, as given by the following:

$$\max_{\mathrm{r_h}}\left(P^{TAC} - AVC_h(r_h)\right)r_h T_h^{TAC} - FC_h\,. \tag{1}$$

Harvesters choose their rate of harvest, r_h^{TAC}, which determines their average variable costs, $AVC_h(r_h^{TAC})$. Market conditions determine the ex-vessel price of fish, P^{TAC}. Harvester fixed costs, FC_h, include vessel costs and moorage. Taking the first order condition of (1) yields:

$$P^{TAC} = MC_h(r_h^{TAC}). \tag{2}$$

Harvesters increase their harvest rate until the marginal cost of their harvest is equal to their marginal revenue, the ex-vessel price P^{TAC}.

As the ex-vessel price is the same for all harvesters, marginal costs for all harvesters must be equal in equilibrium and are determined by (2). Additionally, harvesters aim to produce at their minimum average total costs in the long run by choosing fixed cost investments, $\min ATC_h(r_h^{TAC})$. Harvesters produce such that marginal revenue is equal to $\min ATC_h(r_h^{TAC})$, and harvesters receive zero profit in equilibrium. Harvester quasi-rents, profit plus their fixed costs, are equal to their fixed costs.

Processors

Processors maximize their profit, as given by the following:

$$\max_{r_p}\left(Z - P^{TAC} - AVC_p(r_p)\right) r_p T_p^{TAC} - FC_p\,. \tag{3}$$

Processors choose their rate of harvest, r_p^{TAC}, which determines their average variable costs, $AVC_p(r_p^{TAC})$. The exogenous wholesale price, Z, is the same across all management scenarios as assumed by assumption 8. The ex-vessel price, P^{TAC}, is paid by processors to harvesters. Processor fixed costs, FC_p, include processing plant costs such as leases or the cost of capital. The first order condition of (3) is:

$$Z = P^{TAC} + MC_p\left(r_p^{TAC}\right). \tag{4}$$

Processors increase their processing rate until their marginal revenue, Z, is equal to their marginal cost, the sum of the ex-vessel price and their processing marginal cost.

The wholesale and ex-vessel price are equal for all processors, so marginal costs are equal between processors and determined by (4). As processing cost functions are heterogenous, processing rates are not equal between processors. “High cost” processors produce at lower processing rates than “low cost” processing plants: $r_{p(HC)}^{TAC} < r_{p(LC)}^{TAC}$. Processors aim to produce at their minimum average total costs in the long run, $\min ATC_p(r_p^{TAC})$. Processors receive zero profit in the long run, as their marginal revenue minus the ex-vessel price is equal to their processing costs, $\min ATC_p(r_p^{TAC})$. Processor quasi-rents are relatively large and equal to their fixed cost, as processors generally pay large fixed costs.

Market Clearing

The quantity of fish harvested and processed each season must be equal in equilibrium:

$\sum_m r_{h,m} T^{TAC} = \sum_n r_{p,n} T^{TAC} = TAC$ for M harvesters and N processors, with $r_{h,m}$ indicating the harvest rate for harvester $m \in M$ and $r_{p,n}$ indicating the processing rate for processor $n \in N$. The binding TAC constraint induces a race-to-fish, and the season length will be short: as harvesters are homogenous, $T^{TAC} = \frac{TAC}{r_h^{TAC} M}$. A short season leads to high marginal costs, and as processors will move farther along their marginal cost curves, the ex-vessel price will be relatively low. Harvest rates, processing rates, and ex-vessel price are determined by the following system of three equations:

$$r_h^{TAC} = \frac{1}{M} \sum_n r_{p,n}^{TAC} \tag{5a}$$

$$r_{p,n}^{TAC} = MC_{p,n}^{-1}[Z - MC_h(r_h^{TAC})] \tag{5b}$$

$$P^{TAC} = Z - MC_p\left(r_p^{TAC}\right). \tag{5c}$$

Both harvesters and processors receive zero profit in equilibrium, but processor quasi-rents are very large, due to large fixed costs.

3.3 INDIVIDUAL FISHING RIGHTS (ITQ)

Allocating fishing rights to individual harvesters increases the length of the season and allows harvesters to capture resource rents (Matulich et. al. 1996). These rights can either be transferable (ITQ), the typical case, or non-transferable (IFQ). Harvesters decrease their harvest rate as they are guaranteed a set percentage of the TAC, typically based on historical harvest amounts. During the transitionary period of an ITQ, low ex-vessel prices cause excess demand for. This difference between ex-vessel prices and marginal costs puts upward pressure on ex-vessel prices, generating rent for harvesters. Harvesters receive rent both from increasing ex-vessel prices and from decreased average variable costs as compared to TAC. All rents are generated during the transitory period, until the price of quota is equal to the expected return of quota.

Fisheries that rationalize almost always make fishing quota transferable, so we will analyze an ITQ (Parslow, 2010). Quota transferability increases harvesting efficiency as more efficient vessels buy quota from less efficient vessels. Quota transfers further decrease harvesting costs, increasing overall industry rents.

Harvesters

Harvesters maximize their profit:

$$\max_{\mathrm{r_h}, T_h} \left(P^{ITQ} - AVC_h(r_h)\right) r_h T_h^{ITQ} + s^{ITQ} w_m - FC_h \tag{6}$$

such that $r_h T_h + w_m \leq q_m^{ITQ}$ for some season individual harvest quota q_m^{ITQ}, quota leased w_m, and quota lease price s^{ITQ}. No longer competing for fleet quota, harvesters choose both their harvest rate, r_h^{ITQ}, and their season length, T_h^{ITQ}. Harvesters now maximize their profit by harvesting at the rate that minimizes their average variable cost function: $r_h^{ITQ} = \arg\min_{\mathrm{r_h}} AVC_h(r_h)$. Quota lease prices are determined by the first order condition of (6): $s^{ITQ} = P^{ITQ} - MC_h\left(r_h^{ITQ}\right)$. We assume that harvester cost functions are homogenous, so no quota transfers occur in equilibrium in our model[1].

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[1] “More efficient” heterogenous harvesters with lower marginal costs ($MC_{h,me}\left(r_{h,me}^{ITQ}\right) < MC_{h,le}(r_{h,le}^{ITQ})$) would lease quota ($w_m < 0$) from “less efficient” harvesters as: $s^{ITQ} < P^{ITQ} - MC_{h,me}\left(r_{h,me}^{ITQ}\right)$. “Less efficient” harvesters would lease their quota ($w_m > 0$) as: $s^{ITQ} > P^{ITQ} - MC_{h,le}\left(r_{h,le}^{ITQ}\right)$.

As the harvest rate under open access, r_h^{TAC}, occurred under competition, harvesters will decrease their harvest rate r_h^{ITQ}, which will occur over a season of length $T^{ITQ} > T^{TAC}$. Harvesters will deliver product to processing firms paying the highest ex-vessel price, and may additionally reduce their harvest rate to wait for processing firms to pay higher ex-vessel prices.

In the transitory period, which can last many years, harvesters will receive positive rent; quota prices will be lower than the rate of return on the quota. Eventually, quota sale prices will equal the quota rate of return, and harvester economic rent will be zero. Therefore, all resource rents are generated in the transitory period. Additionally, these gains are realized only by quota holders, who may or may not be vessel owners. Vessel operators may receive skills rent, in addition. High quota prices can result in new fishers being priced out of joining the fishery; for additional discussion on this, see Pálsson and Helgason (1995).

Processors

Processors maximize their profit:

$$\max_{\mathrm{r_p}, T_p} \left(Z - P^{ITQ} - AVC_p\left(r_p\right)\right) r_p T_p^{ITQ} - FC_p\,. \tag{7}$$

Processing rates decrease as harvest rates decrease, lowering marginal costs as compared to TAC: $MC_p\left(r_p^{TAC}\right) > MC_p(r_p^{ITQ})$. This puts upward pressure on the ex-vessel price, which increases until the first order condition of (7) holds: $Z - P^{ITQ} = MC_p(r_p^{ITQ})$.

Processing rates are determined entirely by harvest rates. Operating processors pay marginal costs greater than or equal to their minimum average variable cost: $MC_p\left(r_p^{ITQ}\right) \geq \arg\min_{\mathrm{r_p}} AVC_p(r_p)$. "High-cost" processors, such that $MC_p\left(r_p^{ITQ}\right) = Z - P^{ITQ} <$

$\arg\min_{\mathrm{r_p}} AVC_p(r_p)$, will shut-down. Each additional shut-down of a processing plant makes remaining processing plants more profitable as processing rates increase.

Market Clearing

In equilibrium, the quantity of fish harvested and processed must be equal: $\sum_m r_{h,m}T^{ITQ} = \sum_n r_{p,n}\, T^{ITQ} = TAC$. While the same total amount of fish, the TAC, is harvested and processed across the season, this happens at a much lower daily rate because $T^{ITQ} > T^{TAC}$. The following system of equations determines harvesting rates, processing rates, quota lease price, and ex-vessel prices:

$$r_h^{ITQ} = \arg\min_{\mathrm{r_h^{ITQ}}} AVC_h\left(r_h^{ITQ}\right) \tag{8a}$$

$$\sum_n r_{p,n}^{ITQ} = \sum_m r_{h,m}^{ITQ} \tag{8b}$$

$$s^{ITQ} = P^{ITQ} - MC_h\left(r_h^{ITQ}\right) \tag{8c}$$

$$P^{ITQ} = Z - MC_p\left(r_p^{ITQ}\right). \tag{8d}$$

Processing firm quasi-rents fall well below open access quasi-rents, as the firms operate at $r_p^{ITQ} < r_p^{TAC}$, which corresponds to the zero-profit point. If $P^{ITQ} > Z - AVC_p(r_p^{ITQ})$ for a processing plant, the processing firm will shut down in the short run. In the long run, some processing firms may exit, especially higher-cost processing firms, which may not have quasi-rents high enough to justify staying open to provide jobs to rural communities. Therefore, the processing sector will consolidate over the transitional period, with less processing plants and less communities with processing plant jobs (Agnarsson, 2006; Matulich et. al. 1996). Processing plant closures lower ex-vessel prices as each processing plant has more harvesters, raising marginal processing costs. More industrial, “low-cost” processing plants are likely to survive with relatively high quasi-rents.

3.4 PROCESSOR CENTERED COOPERATIVES (PCC)

Many forms of fishing cooperatives exist, ranging from full vertical integration to restrictions on processing plant delivery. We focus on cooperatives between harvesters and one processing plant, such that harvesters must join a cooperative to receive their individual quota share. As an outside option, harvesters may remain in open access and compete for the non-allocated share of the TAC. Some cooperative management, such as for the Pollock fishery, require that harvesters spend a penalty year in open access between switching cooperatives. Other management, such as for Pacific Cod, allows harvesters to freely switch cooperatives (and processing plants) between years. Such cooperatives, by restricting harvesters to deliver quota only to one processing plant, transfer some market power from harvesters to processors. We will focus on cooperatives without a penalty year; the addition of a penalty year would introduce discounting into harvester cooperative selection.

Harvesters

Harvesters may choose to join a cooperative and receive individual quota shares or remain in a race-to-fish. Harvesters must be better off in the cooperative than TAC to participate in a cooperative, which we may check ex-post. Harvesters may switch cooperatives between seasons, so a processor offering a higher ex-vessel price may attract additional harvesters for the season. Similar to the ITQ, harvesters maximize their profit:

$$\operatorname*{Max}_{\mathrm{r_h}, T_h} \left(P^{PCC} - AVC_h(r_h)\right) r_h T_h^{PCC} + s^{PCC} w_m - FC_h \qquad (9)$$

such that $r_h T_h + w_m \leq q_m^{ITQ}$. The first order condition of (9) determines quota lease prices: $s^{PCC} = P^{PCC} - MC_h(r_h^{PCC})$. Similar to the other individual quota games, harvesters will choose to harvest $r_h^{PCC} = \arg\min_{\mathrm{r_h}} AVC_h(r_h)$.

Active vessels will choose to join a coop if: $[P^{PCC} - AVC_h(r_h^{PCC})] r_h^{PCC} T_h^{PCC} - s^{PCC}(r_h^{PCC} T^{PCC} - r_h^{TAC} T^{TAC} \geq [P^{TAC} - AVC_h(r_h^{TAC})] r_h^{TAC} T^{TAC}$, which may be checked ex-post. Harvesters choose between TAC and the cooperatives each season. In equilibrium, all vessels will choose to join a cooperative. A sole harvester in the TAC quota pool will operate as an individual quota vessel does, harvesting $r_h^{ITQ} = \arg\min_{\mathrm{r_h}} AVC_h(r_h)$.

Processors

Processors compete based on ex-vessel price, similar to an ITQ, maximizing:

$$\max_{r_p, T_p} \left(Z - P^{PCC} - AVC_p\left(r_p^{PCC}\right) \right) r_p^{PCC} T_p^{PCC} - FC_p. \tag{10}$$

Processors may not increase their processing rates by any less than an additional harvester with quota q_m^{ITQ}. Processors taking on an additional harvester face increasing marginal costs, such that $AVC_p\left(r_p^{PCC} + \frac{q_m^{ITQ}}{T^{PCC}}\right) > AVC_p\left(r_p^{PCC}\right)$. Therefore, cooperative processors may be able to lower their ex-vessel prices below ITQ ex-vessel prices by δ^{PCC}, so long as: $\left(Z - (P^{ITQ} - \delta^{PCC}) - AVC_p\left(r_p^{PCC}\right)\right) r_p^{PCC} T^{PCC} \geq \left(Z - (P^{ITQ} - \delta^{PCC}) - AVC_p\left(r_p^{PCC} + \frac{q_m^{ITQ}}{T^{PCC}}\right)\right)\left(r_p^{PCC} + \frac{q_m^{ITQ}}{T^{PCC}}\right) T^{PCC}$. In fisheries with many harvesters for each processor, such that the addition of one more harvester has a negligible effect on average variable processing costs, or where marginal processing costs under ITQ greatly exceed average variable costs, ex-vessel prices in PCC will not fall below ITQ prices. Therefore, the decrease in ex-vessel prices is characterized by:

$$\delta^{PCC} = \max\left\{P^{ITQ} - Z + AVC_p\left(r_p^{PCC} + \frac{q_m^{ITQ}}{T^{PCC}}\right) - \frac{T^{PCC} r_p^{PCC}}{q_m^{ITQ}}\left(AVC_p\left(r_p^{PCC}\right) - AVC_p\left(r_p^{PCC} + \frac{q_m^{ITQ}}{T^{PCC}}\right)\right), 0\right\}. \quad (11)$$

The processor first order condition of (10), $Z - P^{PCC} = MC_p\left(r_p^{PCC}\right)$, will not hold due to positive processor rents.

Instead of opening a cooperative, processors may purchase only from vessels participating in the race-to-fish. Processors may also form a cooperative while still purchasing from harvesters in the TAC. In equilibrium, all harvesters will join a cooperative; therefore, all processors will form cooperatives.

Market Clearing

In addition to the overall market clearing condition: $\sum_m r_{h,m} T^{PCC} = \sum_n r_{p,n} T^{PCC} = TAC$, each individual coop has a market clearing condition: $\sum_m r_{h,m,i}^{PCC} T_h^{PCC} = r_{p,i}^{PCC} T_p^{PCC}$ for coop i. The season length will be determined by harvester minimum average variable costs, such that: $T_h^{PCC} = T_p^{PCC} = T^{PCC}$.

Processors must offer at least $P^{ITQ} - \delta^{PCC}$, as otherwise another processor may pay $P^{PCC} = P^{ITQ} - \delta^{PCC}$ and take on that harvester. The following equations determine the harvest rate, processing rate, quota lease price, and ex-vessel price:

$$r_h^{PCC} = \arg\min_{\mathrm{r_h^{PCC}}} AVC_h(r_h^{PCC}) \quad (12a)$$

$$\sum_{m} r_{h,m,i}^{PCC} T^{PCC} = r_{p,i}^{PCC} T^{PCC} \tag{12b}$$

$$\sum_{m} r_{h,m} = \sum_{n} r_{p,n} \tag{12c}$$

$$s^{PCC} = P^{PCC} - MC_h\left(r_h^{PCC}\right) \tag{12d}$$

$$P^{PCC} = \min\left\{ Z - AVC_p\left(r_p^{PCC} + \frac{q_m^{ITQ}}{T^{PCC}}\right) + \frac{T^{PCC} r_p^{PCC}}{q_m^{ITQ}}\left(AVC_p\left(r_p^{PCC}\right) - AVC_p\left(r_p^{PCC} + \frac{q_m^{ITQ}}{T^{PCC}}\right)\right), P^{ITQ} \right\} \tag{12e}$$

Harvester quasi-rents are lower for cooperatives than or equal to ITQ due to lower-ex vessel prices with the same harvest rates. Processing plant quasi-rents are larger than or equal to ITQ quasi-rents, though not as large as for TAC. Cooperative contracting between processors and harvesters may require processing rates to change from ITQ, as a marginal harvester's quota may not be split up among processors (where a marginal harvester's quota represents any additional processing rate beyond a whole number of harvester's daily rates). Marginal harvester's quota will flow from high-cost processors to low-cost processors, decreasing total processing costs. The decrease in processing costs increases overall industry rents and processing sector rents at the expense of high-cost processor reduced market share.

3.5 Processor Allocated Quota (PAQ)

Allocating some of the TAC quota to processors allows processors to capture some resource rent by gifting or leasing the quota back to harvesters. One-pie splits of quota allocate harvest quota to processors for them to gift back to harvesters, as seen in the Pacific Whiting fishery and Pacific Cod fishery. Two-pie splits instead add separate processor quota into the fishery, such that each processing plant is limited by their processing quota, as seen in the Bering Sea crab fishery. We focus on one-pie splits, as these involve a rent transfer from the harvesting sector to the processing sector. The percentage of the total TAC allocated to processors (α) varies; the Pacific Whiting fishery allocates 20% of total quota to processors and the Pacific Cod fishery allocates 12% to processors (Guldin and Anderson, 2019; McCracken et. al., 2021). Processors gift quota to harvesters as a sort of "frequent flyer mile" for deliveries to their processing plant, gifting harvesters $\frac{\alpha}{1-\alpha}$ shares of quota for every share landed (Guldin and Anderson, 2019). Leasing of processor held quota has not been seen in practice to our knowledge, so we analyze quota gifting.

Harvesters

Harvesters maximize their total profit from the sum of their shares and any shares they are gifted from processors: $\max_{r_h, T_h}\big(P^{PAQ} - AVC_h(r_h)\big)q_m^{PAQ} + \big(P^{PAQ} - AVC_h(r_h)\big)g_i + \big(P^{PAQ} - AVC_h(r_h)\big)w_m + s^{PAQ}w - FC_h$, which simplifies to:

$$\max_{r_h, T_h}\big(P^{PAQ} - AVC_h(r_h)\big)r_h^{PAQ}T_h^{PAQ} + s^{PAQ}w_m - FC_h \tag{13}$$

subject to $T_h^{PAQ}r_h + w_m \leq q_m^{PAQ} + g_i$, such that g_i is the harvest quota gifted from processor i. Note that $q_m^{PAQ} < q_m^{ITQ}$ as α share of the TAC is allocated to the processing sector. Harvest lease prices are determined by the first order condition of (13): $s^{PAQ} = P^{PAQ} - MC_h(r_h^{PAQ})$.

Harvesters choose to deliver to cooperatives offering the best combination of ex-vessel price and gifted quota. In equilibrium $\frac{\alpha}{1-\alpha}$ harvest quota is gifted for each unit of landed fish. Harvesters will deliver to a processor with a lower price than a cooperative that cannot offer them additional quota as long as: $\big[P^{ITQ} - \delta^{PAQ} - AVC_h\big(r_h^{PAQ}\big)\big]r_h^{PAQ}\,\frac{q_m^{PAQ} + \alpha q_m^{PAQ}}{r_h^{PAQ}} \geq$

$\left[P^{ITQ} - AVC_h\left(r_h^{PAQ}\right)\right] r_h^{PAQ} \frac{q_m^{PAQ}}{r_h^{PAQ}}$. Solving for δ^{PAQ}, the maximum difference between ex-vessel prices in ITQ and a processor quota management scheme, yields:

$$\delta^{PAQ} = \frac{\alpha}{1+\alpha} P^{ITQ} - \frac{\alpha}{1+\alpha} AVC_h(r_h). \tag{14}$$

Processors

Processors aim to maximize their total profit, which they do by lowering their ex-vessel price and gifting quota in return for sales of fish:

$$\max_{r_p, T_p} \left(Z - P^{PAQ} - AVC_p\left(r_p^{PAQ}\right)\right) r_p^{PAQ} T_p^{PAQ} - FC_p. \tag{15}$$

Ex-vessel prices are not determined by the first-order condition of (15), as processor allocated quota allows processors to capture resource rent. Instead, ex-vessel prices are determined by equation (14): $P^{PAQ} = P^{ITQ} - \delta^{PAQ}$.

Market Clearing

Total fish processed and harvested must be equal: $\sum_m r_{h,m} T^{PAQ} = \sum_n r_{p,n} T^{PAQ} = TAC$. Additionally, processor-allocated quota allows processors to capture resource rent; ex-vessel prices fall accordingly. The following four equations determine the harvest rate, processing rate, harvest quota lease price, and ex-vessel price:

$$r_h^{PAQ} = \arg\min_{\mathrm{r_h^{PQ}}} AVC_h\left(r_h^{PAQ}\right) \tag{16a}$$

$$\sum_n r_{p,n}^{PAQ} = \sum_m r_{h,m}^{PAQ} \tag{16b}$$

$$s^{PAQ} = P^{PAQ} - MC_h\left(r_h^{PAQ}\right) \tag{16c}$$

$$P^{PAQ} = P^{ITQ} - \frac{\alpha}{1+\alpha}\left(P^{ITQ} - AVC_h\left(r_h^{PAQ}\right)\right) \tag{16d}$$

Processor quasi-rents are higher than in ITQ, though not as high as for TAC; the converse is true for harvesters.

3.6 COOPERATIVES AND PROCESSOR ALLOCATED QUOTA (PQC)

Combining both cooperatives and processor allocated quota allows processors to pay a lower ex-vessel price both through reduced competition between processors due to the cooperatives, and by capturing resource rents from harvest quota.

Harvesters

Harvesters face the same maximization problem as from processor-allocated quota alone:

$$\max_{r_h, T_h}\left(P^{PQC} - AVC_h(r_h)\right) r_h^{PQC} T_h^{PQC} + s^{PQC} w_m - FC_h \tag{17}$$

subject to $T_h^{PQC} r_h + w_m \leq q_m^{PAQ} + g_i$. The first order condition of (17) $s^{PQC} = P^{PQC} - MC_h(r_h^{PQC})$ determines harvest lease prices; processor-allocated quota is gifted.

Harvesters choose to deliver to cooperatives offering the best combination of ex-vessel price and gifted quota. Harvesters will deliver to a processor with a lower price than a cooperative that cannot offer them additional quota as long as: $\left[P^{ITQ} - \delta^{PQC1} - AVC_h\left(r_h^{PQC}\right)\right] r_h^{PQC} \frac{q_m^{PAQ} + \alpha q_m^{PAQ}}{r_h^{PQC}} \geq \left[P^{ITQ} - \delta^{PQC2} - AVC_h\left(r_h^{PQC}\right)\right] r_h^{PQC} \frac{q_m^{PAQ}}{r_h^{PQC}}$, where δ^{PQC1} is the ex-vessel price difference due to processor-allocated quota. Solving for δ^{PQC1}, we obtain:

$$\delta^{PQC1} = \frac{\alpha}{1+\alpha}\left(P^{ITQ} - AVC_h\left(r_h^{PQC}\right)\right). \tag{18}$$

Individual harvest quota is equal to $q_m^{PAQ} < q_m^{ITQ}$ as processors are allocated quota.

Processors

Processors compete based on ex-vessel price, similar to an ITQ, maximizing:

$$\max_{r_p, T_p} \left(Z - P^{PQC} - AVC_p\left(r_p^{PQC}\right)\right) r_p^{PQC} T_p^{PQC} - FC_p\,. \tag{19}$$

Ex-vessel prices, however, do not rise to ITQ prices, as in equilibrium a cooperative i can lower their ex-vessel price by a small amount, δ^{PQC2}, such that cooperative j is no better off by taking an entire additional harvester m on with quota q_m^{PAQ}: $\Big(Z - (P^{ITQ} - \delta^{PQC2}) - AVC_p\left(r_p^{PQC}\right)\Big) r_p^{PQC} T^{PQC} \geq \left(Z - (P^{ITQ} - \delta^{PQC2}) - AVC_p\left(r_p^{PQC} + \frac{q_m^{PAQ}}{T^{PQC}}\right)\right)\left(r_p^{PQC} + \frac{q_m^{PAQ}}{T^{PQC}}\right) T^{PQC}$.

Processors gain additional market rent by lowering their ex-vessel prices, such that other cooperatives are no better off by increasing their own average variable cost to take on an additional harvester. Solving for δ^{PQC2} yields:

$$\delta^{PQC2} = \max\left\{P^{ITQ} - Z + AVC_p\left(r_p^{PQC} + \frac{q_m^{PAQ}}{T^{PQC}}\right) - \frac{T^{PQC} r_p^{PQC}}{q_m^{PAQ}}\left(AVC_p\left(r_p^{PQC}\right) - AVC_p\left(r_p^{PQC} + \frac{q_m^{PQC}}{T^{PQC}}\right)\right), 0\right\}. \tag{20}$$

The processor first order condition, $Z - P^C = MC_p\left(r_p^C\right)$, will not hold due to positive processor rents.

Instead of opening a cooperative, processors may stay in open access. In some cases, they can contract in a cooperative with some harvesters and still buy from other harvesters in open access. In equilibrium, all harvesters will join a cooperative; therefore, all processors will form cooperatives.

Market Clearing

We maintain the same condition for total fish processing and harvesting: $\sum_m r_{h,m} T^{PQC} = \sum_n r_{p,n} T^{PQC} = TAC$. Ex-vessel prices are determined by $P^{PQC} = P^{ITQ} - \delta^{PQC1} - \delta^{PQC2}$. The following five equations determine the harvest rate, processing rate, quota lease price, and ex-vessel price:

$$r_h^{PQC} = \arg\min_{\mathrm{r}_\mathrm{h}^{PQC}} AVC_h\left(r_h^{PQC}\right) \tag{21a}$$

$$\sum_m r_{h,m,i}^{PQC} T^{PQC} = r_{p,i}^{PQC} T^{PQC} \tag{21b}$$

$$\sum_m r_{h,m} = \sum_n r_{p,n} \tag{21c}$$

$$s^{PQC} = P^{PQC} - MC_h\left(r_h^{PQC}\right) \tag{21d}$$

$$P^{PQC} = \min\left\{\begin{matrix} Z - AVC_p\left(r_p^{PQC} + \dfrac{q_m^{PAQ}}{T^{PQC}}\right) + \dfrac{T^{PQC} r_p^{PQC}}{q_m^{PAQ}}\left(AVC_p\left(r_p^{PQC}\right) - AVC_p\left(r_p^{PQC} + \dfrac{q_m^{PQC}}{T^{PQC}}\right)\right) \\ - \dfrac{\alpha}{1+\alpha}\left(P^{ITQ} - AVC_h\left(r_h^{PQC}\right)\right), P^{ITQ} - \dfrac{\alpha}{1+\alpha}\left(P^{ITQ} - AVC_h\left(r_h^{PQC}\right)\right) \end{matrix}\right\}. \tag{21e}$$

Processing plant quasi-rents are expected to be the largest among the individual quota games.

3.7 COMPARISON OF EQUILIBRIUM

Having characterized the equilibrium conditions in each game, we now compare key outcomes across games, including ex-vessel prices, processor and harvester quasi-rents, and how these policies differentially affect high- and low-cost processing firms.

Ex-Vessel Prices

Proposition 1 (Ex-vessel price ranking):

$$P^{TAC} < P^{PQC} \leq \min\{P^{PCC}, P^{PAQ}\} \leq \max\{P^{PCC}, P^{PAQ}\} \leq P^{ITQ}$$

$$P^{PQC} < P^{PCC} \leq P^{ITQ}$$

$$P^{PQC} \leq P^{PAQ} < P^{ITQ}$$

Ex-vessel prices are lowest for TAC, highest for ITQ, and PQC prices are lower than for PCC or PAQ alone.

Lemma 1 (PCC and PAQ prices):

$P^{PCC} > P^{PAQ}$ if and only if: $P^{ITQ} - Z + \frac{T^{PCC} r_p^{PCC}}{q_m^{ITQ}} \left(AVC_p\left(r_p^{PCC} + \frac{q_m^{ITQ}}{T^{PCC}}\right) - AVC_p\left(r_p^{PCC}\right)\right) + AVC_p\left(r_p^{PCC} + \frac{q_m^{ITQ}}{T^{PCC}}\right) < \frac{\alpha}{1+\alpha}\left(P^{ITQ} - AVC_h\left(r_h^{ITQ}\right)\right)$.

The relationship between PCC and PAQ prices depends upon the amount of quota allocated to the processing sector, the number of harvesters compared to processing plants, and the cost functions. In general, the following will impact ex-vessel prices: $\alpha \uparrow \Rightarrow P^{PAQ} \downarrow$; $N \downarrow \Rightarrow P^{PCC} \downarrow$; more steep processing cost functions $\Rightarrow P^{PCC} \downarrow$.

Lemma 2 (PQC price moderation):

$$P^{ITQ} - P^{PQC} < (P^{ITQ} - P^{PAQ}) + (P^{ITQ} - P^{PCC})$$

The price effects of PAQ and PCC moderate each other, such that the price decrease in PQC compared to ITQ is less than both individual effects together.

Proof of Proposition 1: Ex-vessel prices for TAC are lower than for PQC if the following condition is true: $P^{TAC} = Z - MC_p\left(r_p^{TAC}\right) < \min\left\{Z - AVC_p\left(r_p^{PQC} + \frac{q_m^{PAQ}}{T^{PQC}}\right) + \frac{T^{PQC} r_p^{PQC}}{q_m^{PAQ}}\left(AVC_p\left(r_p^{PQC}\right) - AVC_p\left(r_p^{PQC} + \frac{q_m^{PQC}}{T^{PQC}}\right)\right) - \frac{\alpha}{1+\alpha}\left(P^{ITQ} - AVC_h\left(r_h^{PQC}\right)\right), P^{ITQ} - \frac{\alpha}{1+\alpha}\left(P^{ITQ} - AVC_h\left(r_h^{PQC}\right)\right)\right\}$. We begin by showing that when $P^{PQC} = P^{ITQ} - \frac{\alpha}{1+\alpha}\left(P^{ITQ} - AVC_h\left(r_h^{PQC}\right)\right)$ ex-vessel prices for PQC are higher than for TAC. Rearranging yields: $P^{ITQ} - \frac{\alpha}{1+\alpha}\left(P^{ITQ} - AVC_h\left(r_h^{PQC}\right)\right) = \frac{1}{1+\alpha}P^{ITQ} + \frac{\alpha}{1+\alpha}AVC_h\left(r_h^{PQC}\right)$, which is equal to: $\frac{1}{1+\alpha}\left(Z - MC_p\left(r_p^{ITQ}\right)\right) + \frac{\alpha}{1+\alpha}AVC_h\left(r_h^{PQC}\right)$. The zero-profit condition for both harvesters and processors in TAC means that $Z = \min ATC_p\left(r_p\right) + \min ATC_h(r_h)$. Substituting into our equation for P^{PQC}, we have: $\frac{1}{1+\alpha}\left(Z - MC_p\left(r_p^{ITQ}\right)\right) + \frac{\alpha}{1+\alpha}AVC_h\left(r_h^{PQC}\right) = \frac{1}{1+\alpha}\left(\min ATC_p\left(r_p\right) + \min ATC_h(r_h) - MC_p\left(r_p^{ITQ}\right)\right) + \frac{\alpha}{1+\alpha}AVC_h\left(r_h^{PQC}\right)$. Using Assumptions 10 and 11, $\frac{1}{1+\alpha}\left(\min ATC_p\left(r_p\right) + \min ATC_h(r_h) - MC_p\left(r_p^{ITQ}\right)\right) + \frac{\alpha}{1+\alpha}AVC_h\left(r_h^{PQC}\right) \geq \frac{1}{1+\alpha}\left(\min ATC_p\left(r_p\right) + \min ATC_h(r_h) - \frac{1}{2}\min ATC_p\left(r_p\right)\right) + \frac{\alpha}{1+\alpha}AVC_h\left(r_h^{PQC}\right) \geq \frac{1}{1+\alpha}(2\min ATC_h(r_h)) + \frac{\alpha}{1+\alpha}AVC_h\left(r_h^{PQC}\right)$. The second term, $\frac{\alpha}{1+\alpha}AVC_h\left(r_h^{PQC}\right)$ is greater than zero for all $\alpha > 0$, and $\frac{1}{1+\alpha}(2\min ATC_h(r_h)) > \min ATC_h(r_h) = Z - \min ATC_p\left(r_p\right) = P^{TAC}$ for all $\alpha \in (0,1)$. Therefore, for $P^{PQC} = P^{ITQ} - \frac{\alpha}{1+\alpha}\left(P^{ITQ} - AVC_h\left(r_h^{PQC}\right)\right) > P^{TAC}$.

Next, we consider $P^{PQC} = Z - AVC_p\left(r_p^{PQC} + \frac{q_m^{PAQ}}{T^{PQC}}\right) + \frac{T^{PQC} r_p^{PQC}}{q_m^{PAQ}}\left(AVC_p\left(r_p^{PQC}\right) - AVC_p\left(r_p^{PQC} + \frac{q_m^{PQC}}{T^{PQC}}\right)\right) - \frac{\alpha}{1+\alpha}\left(P^{ITQ} - AVC_h\left(r_h^{PQC}\right)\right)$. In this case, we substitute in $P^{ITQ} = Z -$

$MC_p\left(r_p^{ITQ}\right)$ and $Z = \min ATC_p\left(r_p\right) + \min ATC_h(r_h)$ to obtain: $P^{PQC} = \frac{1}{1+\alpha}\left(\min ATC_p\left(r_p\right) + \min ATC_h(r_h)\right) + \frac{\alpha}{1+\alpha} MC_p\left(r_p^{ITQ}\right) + \frac{\alpha}{1+\alpha} AVC_h\left(r_h^{PQC}\right) - AVC_p\left(r_p^{PQC} + \frac{q_m^{PAQ}}{T^{PQC}}\right) + \frac{T^{PQC} r_p^{PQC}}{q_m^{PAQ}}\left(AVC_p\left(r_p^{PQC}\right) - AVC_p\left(r_p^{PQC} + \frac{q_m^{PQC}}{T^{PQC}}\right)\right)$. Using Assumptions 12 and 13, $-AVC_p\left(r_p^{PQC} + \frac{q_m^{PAQ}}{T^{PQC}}\right) + \frac{T^{PQC} r_p^{PQC}}{q_m^{PAQ}}\left(AVC_p\left(r_p^{PQC}\right) - AVC_p\left(r_p^{PQC} + \frac{q_m^{PQC}}{T^{PQC}}\right)\right) \geq -\frac{1}{2} \min ATC_p\left(r_p\right)$, so: $P^{PQC} \geq \frac{1}{1+\alpha}\left(\min ATC_p\left(r_p\right) + \min ATC_h(r_h)\right) + \frac{\alpha}{1+\alpha} MC_p\left(r_p^{ITQ}\right) + \frac{\alpha}{1+\alpha} AVC_h\left(r_h^{PQC}\right) - \frac{1}{2} \min ATC_p\left(r_p\right)$. Rearranging yields: $\frac{1}{1+\alpha} \min ATC_h(r_h) + \frac{1-\alpha}{2(1+\alpha)} \min ATC_p\left(r_p\right) + \frac{\alpha}{1+\alpha} MC_p\left(r_p^{ITQ}\right) + \frac{\alpha}{1+\alpha} AVC_h\left(r_h^{PQC}\right)$, which by applying Assumption 10, is greater than or equal to: $\frac{1}{1+\alpha} \min ATC_h(r_h) + \frac{1-\alpha}{1+\alpha} \min ATC_h(r_h) + \frac{\alpha}{1+\alpha} MC_p\left(r_p^{ITQ}\right) + \frac{\alpha}{1+\alpha} AVC_h\left(r_h^{PQC}\right) = \frac{2-\alpha}{1+\alpha} \min ATC_h(r_h) + \frac{\alpha}{1+\alpha} MC_p\left(r_p^{ITQ}\right) + \frac{\alpha}{1+\alpha} AVC_h\left(r_h^{PQC}\right)$. The first term, $\frac{2-\alpha}{1+\alpha} \min ATC_h(r_h) > \min ATC_h(r_h) = Z - \min ATC_p\left(r_p\right) = P^{TAC}$ for all $\alpha \in \left(0, \frac{1}{2}\right)$, and the second two terms are positive, so $P^{PQC} > P^{TAC}$.

We next show that $P^{PQC} < P^{PCC} \leq P^{ITQ}$. In the case that $P^{PQC} = P^{ITQ} - \frac{\alpha}{1+\alpha}\left(P^{ITQ} - AVC_h\left(r_h^{PQC}\right)\right)$, then $\delta^{PQC2} < 0$. As $q_m^{ITQ} > q_m^{PAQ}$, it must always be true that $\delta^{PCC} = \max\left\{P^{ITQ} - Z + AVC_p\left(r_p^{PCC} + \frac{q_m^{ITQ}}{T^{PCC}}\right) - \frac{T^{PCC} r_p^{PCC}}{q_m^{ITQ}}\left(AVC_p\left(r_p^{PCC}\right) - AVC_p\left(r_p^{PCC} + \frac{q_m^{ITQ}}{T^{PCC}}\right)\right), 0\right\} < \delta^{PQC2} = \max\left\{P^{ITQ} - Z + AVC_p\left(r_p^{PQC} + \frac{q_m^{PAQ}}{T^{PQC}}\right) - \frac{T^{PQC} r_p^{PQC}}{q_m^{PAQ}}\left(AVC_p\left(r_p^{PQC}\right) - AVC_p\left(r_p^{PQC} + \frac{q_m^{PQC}}{T^{PQC}}\right)\right), 0\right\}$. Therefore, if $P^{PQC} = P^{ITQ} - \frac{\alpha}{1+\alpha}\left(P^{ITQ} - AVC_h\left(r_h^{PQC}\right)\right)$, then $P^{PCC} = P^{ITQ}$, and

$P^{PQC} < P^{PCC}$ (see proof that $P^{PAQ} < P^{ITQ}$ below). When $P^{PQC} = Z - AVC_p\left(r_p^{PQC} + \frac{q_m^{PAQ}}{T^{PQC}}\right) + \frac{T^{PQC} r_p^{PQC}}{q_m^{PAQ}}\left(AVC_p\left(r_p^{PQC}\right) - AVC_p\left(r_p^{PQC} + \frac{q_m^{PQC}}{T^{PQC}}\right)\right) - \frac{\alpha}{1+\alpha}\left(P^{ITQ} - AVC_h\left(r_h^{PQC}\right)\right)$, then we must show that $AVC_p\left(r_p^{PCC} + \frac{q_m^{ITQ}}{T^{PCC}}\right) + \frac{T^{PCC} r_p^{PCC}}{q_m^{ITQ}}\left(AVC_p\left(r_p^{PCC} + \frac{q_m^{ITQ}}{T^{PCC}}\right) - AVC_p\left(r_p^{PCC}\right)\right) - AVC_p\left(r_p^{PQC} + \frac{q_m^{PAQ}}{T^{PQC}}\right) - \frac{T^{PQC} r_p^{PQC}}{q_m^{PAQ}}\left(AVC_p\left(r_p^{PQC} + \frac{q_m^{PQC}}{T^{PQC}}\right) - AVC_p\left(r_p^{PQC}\right)\right) < \frac{\alpha}{1+\alpha}(P^{ITQ} - AVC_h\left(r_h^{PQC}\right)$. Let $T = \max\{T^{PQC}, T^{PCC}\}$, $r_p = \max\{r_p^{PQC}, r_p^{PCC}\}$, and $q_m^{PAQ} = q = (1-\alpha)q_m^{ITQ}$. Then the left-hand side is less than or equal to the following, after rearranging: $A = AVC_p\left(r_p + \frac{q}{T}\right) - AVC_p\left(r_p + \frac{(1-\alpha)q}{T}\right) + \frac{Tr_p}{q}\left[AVC_p\left(r_p + \frac{q}{T}\right) - AVC_p\left(r_p\right)\right] - \frac{Tr_p}{(1-\alpha)q}\left[AVC_p\left(r_p + \frac{(1-\alpha)q}{T}\right) - AVC_p\left(r_p\right)\right]$. As average variable costs are concave, $AVC_p\left(r_p + x\right) - AVC_p\left(r_p\right) < x$ for all $x > 0$, so $A < \frac{q}{T} - \frac{(1-\alpha)q}{T} + \frac{Tr_p q}{qT} - \frac{Tr_p(1-\alpha)q}{(1-\alpha)qT} = \frac{q}{T}(\alpha)$. $\frac{q}{T}$ represents the a$f$dditional increase in processing rates from taking on one additional harvester, so according to Assumption 14, this value must be less than or equal to $\frac{1}{2}\left(\min ATC_p\left(r_p\right) - MC_p\left(r_p\right)\right)$. Therefore, $\alpha\frac{q}{T} \leq \alpha\frac{1}{2}\left(\min ATC_p\left(r_p\right) - MC_p\left(r_p\right)\right) < \frac{\alpha}{1+\alpha}\left(\min ATC_p\left(r_p\right) - MC_p\left(r_p\right) + \min ATC_h\left(r_h\right) - AVC_h\left(r_h^{ITQ}\right)\right) = \frac{\alpha}{1+\alpha}\left(P^{ITQ} - AVC_h\left(r_h^{ITQ}\right)\right)$. Therefore, $P^{PQC} < P^{PCC}$. $P^{PCC} \leq P^{ITQ}$ by definition, as $P^{PCC} = \min\left\{Z - AVC_p\left(r_p^{PCC} + \frac{q_m^{ITQ}}{T^{PCC}}\right) + \frac{T^{PCC} r_p^{PCC}}{q_m^{ITQ}}\left(AVC_p\left(r_p^{PCC}\right) - AVC_p\left(r_p^{PCC} + \frac{q_m^{ITQ}}{T^{PCC}}\right)\right), P^{ITQ}\right\}$.

Finally, we show that $P^{PQC} \leq P^{PAQ} < P^{ITQ}$. By definition, $P^{PQC} = \min\left\{Z - AVC_p\left(r_p^{PQC} + \frac{q_m^{PAQ}}{T^{PQC}}\right) + \frac{T^{PQC} r_p^{PQC}}{q_m^{PAQ}}\left(AVC_p\left(r_p^{PQC}\right) - AVC_p\left(r_p^{PQC} + \frac{q_m^{PQC}}{T^{PQC}}\right)\right) - \frac{\alpha}{1+\alpha}\left(P^{ITQ} - AVC_h\left(r_h^{PQC}\right)\right), \frac{1}{1+\alpha}P^{ITQ} + \frac{\alpha}{1+\alpha}AVC_h\left(r_h^{PAQ}\right)\right\} \leq P^{PAQ} = \frac{1}{1+\alpha}P^{ITQ} + \frac{\alpha}{1+\alpha}AVC_h\left(r_h^{PAQ}\right)$. ITQ prices are higher than PAQ prices if: $P^{ITQ} > P^{PAQ} = P^{ITQ} - \frac{\alpha}{1+\alpha}\left(P^{ITQ} - AVC_h\left(r_h^{PAQ}\right)\right)$. Harvesters operate at minimum average variable costs, so $P^{ITQ} - AVC_h\left(r_h^{PAQ}\right) > 0$. Specifically, $P^{ITQ} = s^{ITQ} + MC_h\left(r_h^{ITQ}\right) > MC_h\left(r_h^{ITQ}\right) = MC_h\left(r_h^{PAQ}\right) = AVC_h\left(r_h^{PAQ}\right)$. Therefore, for all $\alpha \in (0,1)$, $P^{ITQ} > P^{PAQ}$.

Explanation of Lemma 1: The equation for price comparison between P^{PAQ} and P^{PCC} follows from $\delta^{PAQ} = \frac{\alpha}{1+\alpha}\left(P^{ITQ} - AVC_h\left(r_h^{PAQ}\right)\right)$ and $\delta^{PCC} = \min\left[P^{ITQ} - Z + AVC_p\left(r_p^{PCC} + \frac{q_m^{ITQ}}{T^{PCC}}\right) - \frac{T^{PCC} r_p^{PCC}}{q_m^{ITQ}}\left(AVC_p\left(r_p^{PCC}\right) - AVC_p\left(r_p^{PCC} + \frac{q_m^{ITQ}}{T^{PCC}}\right)\right), 0\right]$. $P^{PCC} = P^{ITQ} - \delta^{PCC} > P^{PAQ} = P^{ITQ} - \delta^{PAQ}$ if and only if: $P^{ITQ} - Z + \frac{T^{PCC} r_p^{PCC}}{q_m^{ITQ}}\left(AVC_p\left(r_p^{PCC} + \frac{q_m^{ITQ}}{T^{PCC}}\right) - AVC_p\left(r_p^{PCC}\right)\right) + AVC_p\left(r_p^{PCC} + \frac{q_m^{ITQ}}{T^{PCC}}\right) < \frac{\alpha}{1+\alpha}\left(P^{ITQ} - AVC_h\left(r_h^{ITQ}\right)\right)$.

An increase in the percentage of the quota TAC allocated to the processing sector (α) will decrease ex-vessel prices, as $\delta^{PAQ} = \frac{\alpha}{1+\alpha}\left(P^{ITQ} - AVC_h\left(r_h^{PAQ}\right)\right)$ will decrease as α increases. A decrease in the number of processors (n), or increase in the number of harvesters (m), increases $\frac{T^{PCC} r_p^{PCC}}{q_m^{ITQ}}$ as each cooperative takes on additional harvesters. Therefore, as processing rates r_p^{PCC} increase, average variable costs increase, and the difference in average variable costs

$AVC_p\left(r_p^{PCC}+\frac{q_m^{ITQ}}{T^{PCC}}\right)-AVC_p\left(r_p^{PCC}\right)$ increases, yielding a decrease in P^{PCC}. More steep processing cost functions increase the difference in average variable costs $AVC_p\left(r_p^{PCC}+\frac{q_m^{ITQ}}{T^{PCC}}\right)-AVC_p\left(r_p^{PCC}\right)$, decreasing the ex-vessel price P^{PCC}.

Explanation of Lemma 2: The impacts of combining processor quota and cooperatives moderate each other due to the lower increase in daily processing rates for processors to take on an additional harvester as compared to games with $q_m^{ITQ} > q_m^{PAQ}$: $\delta^{PQC1}+\delta^{PQC2} = \min\left\{\frac{\alpha}{1+\alpha}\left(P^{ITQ}-AVC_h\left(r_h^{PQC}\right)\right)+P^{ITQ}-Z+AVC_p\left(r_p^{PQC}+\frac{q_m^{PAQ}}{T^{PQC}}\right)-\frac{T^{PQC}r_p^{PQC}}{q_m^{PAQ}}\left(AVC_p\left(r_p^{PQC}\right)-AVC_p\left(r_p^{PQC}+\frac{q_m^{PQC}}{T^{PQC}}\right)\right), \frac{\alpha}{1+\alpha}\left(P^{ITQ}-AVC_h\left(r_h^{PQC}\right)\right)\right\} < \delta^{PAQ}+\delta^{PCC} = \frac{\alpha}{1+\alpha}\left(P^{ITQ}-AVC_h\left(r_h^{PAQ}\right)\right)+\min\left[P^{ITQ}-Z+AVC_p\left(r_p^{PCC}+\frac{q_m^{ITQ}}{T^{PCC}}\right)-\frac{T^{PCC}r_p^{PCC}}{q_m^{ITQ}}\left(AVC_p\left(r_p^{PCC}\right)-AVC_p\left(r_p^{PCC}+\frac{q_m^{ITQ}}{T^{PCC}}\right)\right), 0\right]$.

Between Industry Quasi-Rent Comparison

Proposition 2 (Quasi-rent ranking):

$$FC_h = \pi_h^{TAC} < \pi_h^{PQC} < \min\{\pi_h^{PCC}, \pi_h^{PAQ}\} \leq \max\{\pi_h^{PCC}, \pi_h^{PAQ}\} < \pi_h^{ITQ}$$

$$FC_p = \pi_p^{TAC} > \pi_p^{PQC} > \max\{\pi_p^{PCC}, \pi_p^{PAQ}\} \geq \min\{\pi_p^{PCC}, \pi_p^{PAQ}\} > \pi_p^{ITQ}$$

Overall processing industry quasi-rents (π_p) and harvesting industry quasi-rents (π_h) are analogous to the ordering of ex-vessel prices, with opposite effects.

Proof of Proposition 2: Harvester quasi-rents in the TAC game equal: $\pi_h^{TAC} = \left(P^{TAC} - AVC_h(r_h^{TAC})\right) r_h^{TAC} T^{TAC}$ and harvester quasi-rents in individual quota games equal: $\pi_h = (P - \min AVC_h(r_h)) r_h T + sw_m$. Based on Assumption 5, the TAC is allocated proportionally between harvesters such that for any individual quota game: $r_h^{TAC} T^{TAC} = r_h T$. Therefore, as both $P^{TAC} < P^{PQC}$ and $AVC_h(r_h^{TAC}) > \min AVC_h(r_h)$, $\pi_h^{TAC} < \pi_h^{PQC}$. Between the individual quota games, only ex-vessel prices will vary, as in equilibrium no quota is traded ($w_m = 0$). Therefore, given that: $P^{PQC} \leq \min\{P^{PCC}, P^{PAQ}\} \leq \max\{P^{PCC}, P^{PAQ}\} \leq P^{ITQ}$, it must be true that: $\pi_h^{PQC} < \min\{\pi_h^{PCC}, \pi_h^{PAQ}\} \leq \max\{\pi_h^{PCC}, \pi_h^{PAQ}\} < \pi_h^{ITQ}$.

Processor quasi-rents equal: $\pi_p = \left(Z - P - AVC_p(r_p)\right) r_p T$. The wholesale price, Z, is the same every game, so only ex-vessel prices, processing rates, and season length change. The processing industry overall processes the same total TAC in every game, such that $r_p T$ is equal between all games. Therefore, processor TAC quasi-rents are larger than for PQC if: $Z - P^{TAC} - AVC_p(r_p^{TAC}) > Z - P^{PQC} - AVC_p(r_p^{PQC})$. Processors choose a processing rate such that they are operating at the minimum average total cost in the TAC game, such that: $Z - P^{TAC} = MC_p(r_p^{TAC}) = \min ATC_p(r_p^{TAC})$. Quasi-rents in the TAC game can be solved for: $\min ATC_p(r_p^{TAC}) - AVC_p(r_p^{TAC}) > MC_p(r_p^{PQC}) - AVC_p(r_p^{PQC})$ as marginal costs rise at a faster rate than average variable costs. Therefore, $\pi_p^{TAC} > \pi_p^{PQC}$. The ex-vessel price ranking for all other games determines the ranking of quasi-rents, as industry wide processing rates are determined solely by harvesters.

Heterogenous Processing Firm Quasi-Rents

Lemma 3: Rationalization and cost functions

$$\%\Delta r_{p,lc} < \%\Delta r_{p,hc}, \Delta r_p = r_p^{TAC} - r_p^{ITQ}$$

The percentage change in daily processing rates for high-cost firms ($\%\Delta r_{p,hc}$) from moving from a TAC to an ITQ is larger than for low-cost firms ($\%\Delta r_{p,lc}$).

Proposition 3: Policies and high-cost daily processing rates

$$\%\Delta r_{p,hc}^{PCC} < 0 < \%\Delta r_{p,hc}^{PAC} < \%\Delta r_{p,hc}^{PQC}, \Delta r_{p,hc}^{GAME} = r_{p,hc}^{GAME} - r_{p,hc}^{ITQ}$$

Compared to ITQ, high-cost processors process lower daily processing rates in PCC, process more daily in PAC, and process the most in PQC.

Explanation of Lemma 3: When rationalizing, daily harvest rates fall very quickly in a dramatic way, causing a season lengthening and decreasing processing rates: $r_h^{ITQ} = argmin_{r_h} AVC(r_h) < r_h^{TAC} = argmin_{r_h} ATC(r_h); r_p^{ITQ} < r_p^{TAC}$. The actual change in processing rates for processors with heterogenous cost functions depends upon a change in marginal costs, as processing rates in TAC and ITQ are determined by the following equations: $r_p^{TAC} = MC_p^{-1}[Z - P^{TAC}]$ and $r_p^{ITQ} = MC_p^{-1}[Z - P^{ITQ}]$. As the following figure shows, the same change in marginal costs for both a low-cost and a high-cost processor causes different changes in the processing rates for both firms, with a larger percentage change in high-cost firms daily processing rate. This result follows from increasing marginal costs.

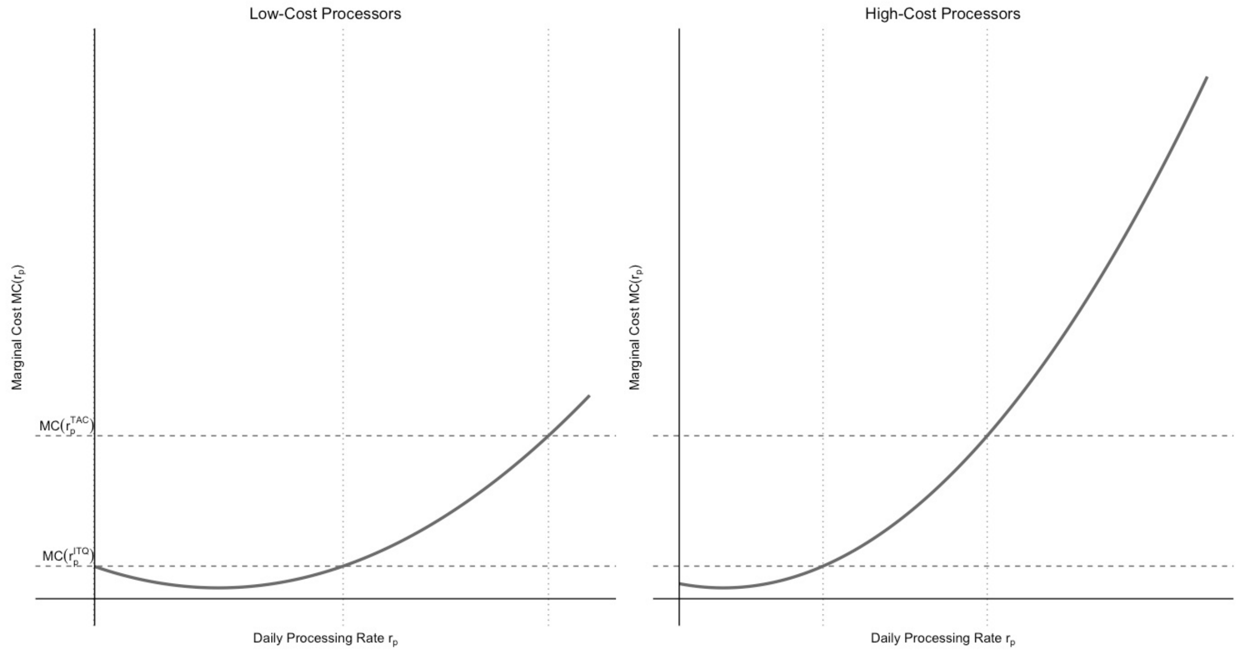

Figure 1: Low-cost versus high-cost processing plant marginal costs in TAC and ITQ

Proof of Proposition 3: Cooperatives alone lower ex-vessel prices by requiring processors to take on an entire harvester's quota, q_m^{ITQ}, to increase their processing rates. High-cost processors operate farther along their marginal cost cure (farther from their minimum average variable cost), so must pay a larger increase in average variable cost to take on an additional harvester: $AVC_p\left(r_{p,hc}^{PCC}+\frac{q_m^{ITQ}}{T^{PCC}}\right)-AVC_p\left(r_{p,hc}^{PCC}\right)>AVC_p\left(r_{p,lc}^{PCC}+\frac{q_m^{ITQ}}{T^{PCC}}\right)-AVC_p\left(r_{p,lc}^{PCC}\right)$.

Processor-allocated quota initial allocations are based on TAC processing rates typically, which benefits high-cost firms slightly more than low-cost firms. High-cost firms process a much larger share of the TAC in TAC than in individual quota games such as ITQ, so $\%\Delta r_{p,hc}^{PAC}>0$ as the amount of quota allocated to a high-cost plant is larger than their expected share in ITQ. The combined game, PQC, has the largest positive impact on high-cost processor rates compared to

ITQ, as high-cost processors both are allocated TAC levels of processor quota and guaranteed entire harvester quota shares due to the cooperatives.

4 DISCUSSION

Our results explain how market power shifts from the processing sector to the harvesting sector after season lengthening and the introduction of individual harvesting rights. A large shift in market power occurs without a policy intervention such as cooperatives or processor quota (Matulich et. al. 1996), which may be seen as an undesirable outcome for vulnerable firms. We model equilibrium ex-vessel prices and daily processing and harvesting rates under several management schemes including processor-allocated quota, processor centered cooperatives, and a combination of the two. We characterize quasi-rents for each sector under each management system, and analyze how the policies differentially impact processing firms with heterogenous cost functions.

We found that these policies differentially impact harvesters and processors and different firms within the processing sector in ways that may be very important for management. As expected, processor-allocated quota and processor centered cooperatives transfer rent from the harvesting to the processing sector as compared to an individual transferable quota alone, due to decreases in ex-vessel prices. Even for a combination of the two policies, these outcomes moderate each other and do not approach total allowable catch ex-vessel prices or quasi-rents, ensuring that desirable features of individual transferable quotas remain for the harvesting sector, albeit to a lesser degree. Increased quasi-rents for the processing sector may delay or even stop some processing plant closures as compared to an individual transferable quota system alone. Each processing plant closure increases quasi-rents of remaining processing plants; some processing plants, particularly larger more industrial ones, will survive and obtain zero-profit after a transitory period. While some processing plant closures may be economically efficient, particularly for high-cost processing plants, plant closures may be at odds with management goals such as community protection and local jobs.

Although processor-allocated quota and processor centered cooperatives transfer rent to the processing sector, these gains are not felt equally across the processing sector. Rising marginal costs transfer a large percentage of high-cost processing plant market share in total allowable catch systems from high-cost plants to low-cost processing plants, further hurting high-cost plants operating in individual transferable quota systems. Processor quota and cooperative decreases in ex-vessel prices compared to individual transferable quotas have a positive impact on all processing firms, but processor centered cooperatives actually further reduce high-cost processing firm market share compared to individual transferable quotas alone. Processor quota has a small impact on processor market share, resulting in small potential gains for high-cost processors that are unlikely to change firm survival in a large way. Combining processor-allocated quota and processor centered cooperatives, on the other hand, transfers a much larger market share to high-cost processing plants, resulting in larger quasi-rents for high-cost plants compared to all other harvest quota rights markets. While quasi-rents are not likely to approach total allowable catch levels of quasi-rents, the resulting rent transfer may positively impact high-cost processing plant survival, at least in a transitory period.

Management concerns about processing plant closures and high-cost, vulnerable, processing firms has resulted in the institution of processor-allocated quota and processor centered cooperative policies. Previous research on processor harvester relationships often focused on vertical integration, a common outcome of early individual transferable quotas (Gunnlaugsson and Valtysson 2022). Our model expands on Matulich and Sever's (1999) analysis processor-allocated quota by allowing for processor quota to be gifted instead of leased, as documented to occur in the Pacific Whiting fishery (Guldin and Anderson 2019). Matulich et al. (2001) modelled processor centered cooperatives, and we relax their assumptions about processor-harvesting bargaining to model a competitive equilibrium. We do not know of any other research that models a combined policy of processor-allocated quota and cooperatives, first implemented in the Pacific Cod fishery in 2023. Our research shows that instead of magnifying each other, processor quota and cooperative effects moderate each other in a combined policy, resulting in slightly higher ex-vessel prices.

Fisheries rationalization is likely to lead to some industry consolidation on the processing side, which may occur over years, often pre-rationalization, as discussed by Wilen (2009). In cases with industrial processing plants, some processing plant closures or line closures may be economically efficient and desirable. Yet, many small, rural, communities depend on processing plants for jobs, revenue, and local harvesters; this issue is often missed by researchers such as Professor Wilen and Professor Matulich in their discussion about stranded capital (Matulich, 2010; Wilen, 2010). Our model shows that fisheries rationalization differentially impacts high- and low-cost processing plants, leading to large losses for high-cost plants in particular. Although economically efficient, high-cost processing plant closures may be at odds with management goals such as coastal community protections for indigenous and non-indigenous small communities.

Policymakers face a challenge of determining the proper amount of community protection for fisheries introducing individual harvesting rights. Our results show that processor-allocated quota and processor centered cooperatives alone do not sufficiently protect high-cost processing plants as compared to individual transferable quotas; in fact, processor centered cooperatives may actually be worse for high-cost processors. Combining these two policies has the best likelihood of leading to large gains for high-cost processing plants as compared to other harvest quota rights models. We recommend that managers concerned about high-cost processors consider combining these two policies, even if at low levels such as less than 10-15% of the total quota allocated to the processing sector and implementations of cooperatives without a penalty year. Though these policies transfer some rent from the harvesting to the processing sector as compared to individual transferable quotas alone, the combined policy does not transfer drastically more rent than either policy alone and is much more likely to benefit high-cost processing firms.

We suggest that future research also considers the impact of fisheries policy on processing firms with heterogenous cost functions; because, as we have shown, these policies may differentially impact firms essential to other management goals such as coastal community protections. Our model includes only several of a wide variety of policies, including cooperatives with a penalty year implementation, cooperatives that allow for some level of vertical integration, and two-pie splits of processor quota. We suggest that in addition to research analyzing these other policy implementations, research focuses on empirical estimations of the impacts of these policies.

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Rent Splitting after Rationalization: An Experimental Analysis

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1. INTRODUCTION

Allocating resource harvest rights dramatically impact the distribution of rent between and within fisheries sectors. Fisheries managers chose to implement rationalization schemes in an effort to improve harvester safety and profit (Kearney, 2001). Concerns about impacts on the processing sector led some fisheries to implement rationalization with a cooperative requirement or by allocated some harvest quota to the processing sector. We analyze how processor-allocated quota (PAQ) and processor centered cooperative (PCC) rationalization impact industry outcomes. Typically introduced in conjunction with fisheries rationalization, when harvest quota is allocated to individual harvesters, "one-pie" splits of PAQ (Matulich and Sever, 1999) and PCC (Matulich et al., 2001) shift less rent from the processing sector to the harvesting sector than standard individual transferable quota (ITQ) rationalization. Our results indicate that PAQ and PCC alone and combined do not result in rent splitting between the harvesting and processing sectors that approaches total allowable catch (TAC) or "race-to-fish" levels of rent to the processing sector. Additionally, while PAQ and PCC alone do improve processing sector outcomes, only combining processor-allocated quota and processor centered cooperatives (PQC) yields measurable improvements for higher-cost processing firms. Our research complements theoretical research about these policy interventions (Matulich et al., 1996; Matulich and Sever, 1999; Matulich et al. 2001; Schamp Chapter 2).

Fisheries rationalization has the potential to yield enormous ecological and economic gains (Townsend and Pooley, 1995; Costello et al., 2008; Arnason and Runolfsson, 2023); yet, rationalization can also lead to negative social outcomes (Hoshino et al., 2020). Although processor quota and cooperative additions to rationalization may seem unusual, several large fisheries implemented them, including: Pacific Whiting (*Mercluccius productus)*, Alaskan

Pollock (*Gadus chalcogrammus)*, and Pacific Cod (*Gadus macrocephalus)*. Often instituted to protect the processing sector, cooperatives and processor quota shift unknown amounts of rent from the harvesting to the processing sector, as compared to individual harvest quota rationalization alone. Although these policies may be intended to combat a worrying string of processing plant closures off the West Coast[1] due to rationalization and lower fisheries yield, as compared to historic yields, these policies may differentially affect processing firms with heterogenous cost functions. High-cost, often rural and vulnerable, processing plants may be important to management due to fishery proximity or important local jobs, and may be particularly vulnerable to closure due to standard quota rationalization (Lyons et al., 2016). We pay special attention to the differential impact of these policies within the processing sector, in addition to the impact on rent transfers between harvesting and processing sectors.

Theoretical discussions of processor quota and cooperative policies include: Schamp Chapter 2 for analysis of the combined policy and specifics of processor quota gifting, Matulich and Sever (1999) for discussion of "one -pie" splits of processor quota that is leased back to harvesters, and Matulich et al. (2001) for discussion of cooperative formation specific to the American Fisheries Act in the Alaskan Pollock fishery. Processor leasing or gifting of quota may both seem plausible, so we test a specification based on evidence from the Pacific Whiting fishery that suggests that processors gift the quota to make harvesters "whole" for every partial share of quota harvesters land (Guldin and Anderson, 2019). The Pacific Cod 2023 rationalization combined both processor cooperatives and processor quota, a specification not

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[1] https://www.fisheries.noaa.gov/feature-story/economic-snapshot-shows-alaska-seafood-industry-suffered-18-billion-loss-2022-2023; https://kmun.org/seafood-plant-closures-spell-uncertainty-for-fishing-community/; https://alaskapublic.org/news/2024-10-10/st-paul-seafood-processing-facility-unlikely-to-reopen-for-surprise-snow-crab-fishery; https://www.kucb.org/2024-07-19/king-cove-hit-hard-by-seafood-cannery-closure

tested to our knowledge, with unknown impacts on rent distribution within and between sectors (McCracken et al., 2021).

The use of laboratory studies to assess fisheries management and institutions show that choice of exact management can have large impacts on the ability for markets to reach an equilibrium and market variability (Anderson, 2004; Anderson and Sutinen, 2005). Similar to how Anderson and Sutinen (2006) evaluated both a central call market and initial lease period individually and combined impact quota price variability, we evaluate cooperatives and processor quota individually and together. Anderson et al. (2008) evaluated consolidation, a potential negative social outcome of ITQs, as a response to underlying market fundamentals, finding the possibility of diffusion. Other laboratory experiments include Moxnes (2012), who tested individual assigned quotas versus yearly quota auctions, Tisdell and Iftekhar (2013), who tested ITQs in a multi-species context, and Tanaka et al. (2014), who considered vessel size.

We tested how processor quota and cooperatives impact the distribution of rent both between harvesting and processing sectors and within the processing sector for processing firms with heterogenous cost functions using a laboratory experiment. Using a processor posted offer market experiment with five different games, one “race-to-fish” game (TAC) and four quota rationalization games, we estimate ex-vessel prices and firm profit. Rationalization games included a standard game (ITQ), cooperatives (PCC), processor quota (PAQ), and a combined game with both cooperatives and processor quota (PQC). We evaluate welfare outcomes for homogenous harvesters and heterogenous processors based on our estimates for ex-vessel prices and firm profit. We additionally evaluate high- versus low-cost processor market share measured by the number of units processed per game day in each game to explain differences between profit for processing firms.

Section two introduces our theoretical model and calibrations for cost functions. Section three explains our experimental design. Section three describes our results. Section four concludes.

2. THEORETICAL MODEL PREDICTIONS

Theoretical ex-vessel prices are based on Matulich et al. (1996) and the framework introduced in Chapter 2. The following equations characterize ex-vessel prices in each game:

$$P^{TAC} = Z - MC_p\left(r_p^{TAC}\right) \qquad (1)$$

$$P^{ITQ} = Z - MC_p\left(r_p^{ITQ}\right) \qquad (2)$$

$$P^{PCC} = \min\left\{Z - AVC_p\left(r_p^{PCC} + \frac{q_m^{ITQ}}{T^{PCC}}\right) + \frac{T^{PCC} r_p^{PCC}}{q_m^{ITQ}}\left(AVC_p\left(r_p^{PCC}\right) - AVC_p\left(r_p^{PCC} + \frac{q_m^{ITQ}}{T^{PCC}}\right)\right), P^{ITQ}\right\} \qquad (3)$$

$$P^{PAQ} = P^{ITQ} - \frac{\alpha}{1+\alpha}\left(P^{ITQ} - AVC_h\left(r_h^{PAQ}\right)\right) \qquad (4)$$

$$P^{PQC} = \min\left\{\begin{array}{c} Z - AVC_p\left(r_p^{PQC} + \frac{q_m^{PAQ}}{T^{PQC}}\right) + \frac{T^{PQC} r_p^{PQC}}{q_m^{PAQ}}\left(AVC_p\left(r_p^{PQC}\right) - AVC_p\left(r_p^{PQC} + \frac{q_m^{PQC}}{T^{PQC}}\right)\right) \\ - \frac{\alpha}{1+\alpha}\left(P^{ITQ} - AVC_h\left(r_h^{PQC}\right)\right), P^{ITQ} - \frac{\alpha}{1+\alpha}\left(P^{ITQ} - AVC_h\left(r_h^{PQC}\right)\right) \end{array}\right\} \qquad (5).$$

All ex-vessel prices are uniquely determined by the wholesale price Z, harvesting and processing rates r_h & r_p, marginal and average variable cost functions MC & AVC, season length T, quota allocated to harvesters, q_m, and the percentage of the quota allocated to processors α. Chapter 2 Proposition 1 defines the ex-vessel price ranking as follows: $P^{TAC} < P^{PQC} \leq \min\{P^{PCC}, P^{PAQ}\} \leq \max\{P^{PCC}, P^{PAQ}\} \leq P^{ITQ}$. The exact ranking of P^{PCC} and P^{PAQ} depends upon average variable costs and the percentage of the TAC allocated to the processing sector.

We obtained participant payoff functions by calibrating our model using a total TAC quota of 360 units, and \$20 wholesale price marginal revenue (MR) for processors, and a \$5 equilibrium price in the TAC game. We assumed harvesters were homogenous, so only calibrated one set of harvesting costs, while we calibrated cost functions for a high-cost and for a low-cost processor. Our experiment was calibrated for two low-cost processors, two high-cost processors, and nine harvesters. We chose an uneven number of harvesters for each processor to gain additional information about marginal harvesters.

We calibrated marginal cost using the following function form: $a(r_t - b)^2 + c$, where $a = 0.0044, 0.0014, 0.0039$, $b = 10, 10, 10$, and $c = 1, 1, 1$ for harvesters, low-cost processors, and high-cost processors, respectively. We calculated a for each participant based on arbitrarily chosen single day rates in the TAC game of 40 units for harvesters, 110 units for low-cost processors, and 70 units for high-cost processors. Additionally, $MC = MR$ implies that for a \$5 equilibrium ex-vessel price, harvester marginal costs are \$5 and processor marginal costs are \$15. Therefore, $a = \frac{MC(r_t)-c}{(r_t-b)^2}$ for each participant. Average variable costs equal the sum of marginal costs (variable costs) divided by the processing or harvesting rate.

In the steady-state under a TAC, harvesters and processors make zero profit including fixed costs. If processor fixed costs are lower and they make positive profit, new entrants (or additional processing lines for existing processors) will raise the ex-vessel price until firms make zero profit. The reverse argument implies firms will exit in the long-run if they make negative profit, and a similar argument can be made for harvesters. Therefore, firms will pay a fixed cost such that their average total cost is equal to their marginal revenue (including ex-vessel price for processors) and make zero profit in the steady state. We therefore calculated fixed-costs to ensure average total costs equal marginal costs in the TAC game, as firms produce at minimum average total costs in the long-run. Our calculated fixed costs are: \$117, \$1066, and \$692 for harvesters, low-cost, and high cost processors, respectively. Average total costs equal variable costs plus fixed costs divided by the daily processing or harvesting rate.

No participant decisions are based on fixed costs in our experiment, and participants may be frustrated if they receive zero profit. Additionally, processors making zero profit in the TAC game are expected to make negative profit in all other games, so we do not include or mention fixed costs within our experiment. Participant equilibrium profit in the TAC game should approximately equal fixed costs.

Our entire experiment occurs within a steady-state fish stock scenario. The total TAC remains the same within all games, whether it is 360 units in the fleet quota, 40 units allocated to each of the nine harvesters, or 32 units allocated to each harvester and 18 units allocated to each of the four processors. We consider only steady stocks to reduce the complexity of the experiment and as many stocks for which the policies are relevant remain in steady state, such as Pacific Pollock.

Firms that can choose their production level, i.e., harvesters with individual harvesting rights, will choose to produce at their minimum average variable cost (AVC). Our calibration yields a minimum average variable cost of 14 units for harvesters and 14 units for both low-cost and high-cost processors. Yet, daily processing rates are dependent upon daily harvesting rates, as many fish products must be processed the day it arrives, such as the case for crab, or may be higher value if processed as fresh product. Our experiment requires that total daily harvest equals total daily processing, causing processors to operate well above their minimum AVC when harvesters can choose their daily harvest rate.

Ex-vessel prices depend upon harvesting and processing rates. Predicted ex-vessel prices for each game are presented in Table 1. TAC harvesting rates are larger than for individual quota games, as the game is calibrated for the entire TAC to be harvested in one day. For individual quota games, processing rates are chosen to ensure 126 units are processed daily, 14 for each of the nine harvesters. In ITQ and PAQ, processing marginal costs for high and low-cost processing plants must be equal at each of their respective processing rates. Cooperative games require that each processor has a whole number of harvesters in their cooperative. Processing rates may not be a multiple of 14 when, for instance, one low-cost processor has three harvesters, and another has two harvesters. Processor quota games are calibrated with 20% of the quota allocated to the processing sector, with processors utilizing the quota optimally. Some processors had trouble utilizing the processor quota gift mechanism, which could impact ex-vessel prices in games with processor quota. If only half of the processor quota is used optimally, or $\alpha = 10\%$, then predicted ex-vessel prices for PAQ and PQC are \$16.37 and \$16.33, respectively.

Table 1: Predicted Ex-Vessel Prices and Harvesting and Processing Rates

	Ex-Vessel Price	Season Length	Harvesting Rate	Low-Cost Rate	High-Cost Rate
TAC	\$5.00	1	40	110	70
ITQ	\$17.90	2.85	14	38	25
PCC	\$16.81	2.85	14	42	21
PAQ	\$15.10	2.85	14	38	25
PQC	\$15.05	2.85	14	33	30

3. EXPERIMENTAL DESIGN

We tested how processor-allocated quota and cooperatives impact markets by using a controlled laboratory experiment in which 65 subjects acted as fishery processors and harvesters. During the our five experimental sessions, participants acting as harvesters sell fish to participants acting as processors, subject to several different market structures. The first game functions as a “race-to-fish”, and subsequent games allocate harvest quota to each harvester. During each fishing day, participants choose how much fish to sell (buy) for a price they offer (accept). Similar to a commercial fishery, participants that better balance increasing daily costs and harvest quotas earn more total profit and therefore are paid more for participating.

Each experimental session played four different games. Due to the complexity of games involving individual quota, particularly once cooperatives and processor quota were introduced, games were not ordered in a Latin square. All sessions began with the TAC game, and then introduced individual harvester quota with the ITQ game. Each session played two of the harvest games with interventions, PCC, PAQ, or PQC. Participants reviewed overall instructions and TAC specific instructions such as fleet quota prior to Game 1 and received game specific instructions that introduced each new market rule for Games 2-4. Table 2 shows which sessions played which games, and the order of the games.

Table 2: Sessions and Games

Session	Game 1	Game 2	Game 3	Game 4
1	TAC	ITQ	PAQ	PQC
2	TAC	ITQ	PAQ	PQC
3	TAC	ITQ	PCC	PQC
4	TAC	ITQ	PCC	PQC
5	TAC	ITQ	PCC	PAQ

The instructions for each game built upon previous game mechanisms; thus, significant learning occurred over the course of each experimental session, so we did not vary the order of the games. Instead, we accounted for ordering impacts by introducing an inflationary value of money within each game (Kagel et al., 1987). All costs, wholesale prices, ex-vessel prices, and profits are reported for our standardized value of money; wholesale prices were drawn from a uniform distribution ranging from $10 to $40. Additionally, we test how the wholesale price and the difference in the wholesale price from the previous game influence ex-vessel prices, finding small impacts.

Each game was made up of 4 fishing seasons with three days per season. Four periods has been shown to be enough for markets to converge (Davis and Holt, 2021). The first day in the first season of the TAC game lasted five minutes, and time decreased each day thru each season to 90 seconds per day. The following games also featured longer times for early season days. These times were chosen based on pilot tests and indicate that all trades that would have occurred did occur within these time limits. Participant profits were determined by the amount of fish sold (bought) per day, a per-day cost function, and fish prices. The game automatically sold all processed fish at a set wholesale price of $20 in all games. We did not include any improvements in fish processing with longer seasons.

We used a processor posted-price market, with processors submitting offers for a quantity of fish at an offer price that all harvesters see. In non-coop games, any harvester can accept any processor offer, up to the quantity offered subject to the individual or fleet quota constraint. Processors can see their current offer, including the quantity remaining, and all other current offers. When a harvester accepted less than the maximum quantity a processor offered, the offer remained available to other harvesters at the same price for the remaining quantity. Once a harvester accepts an offer, the fish quota is immediately reduced by the quantity accepted, and profit is realized for both the harvester and processor. Harvesters do not make a separate decision to harvest fish quota until they accept a transaction; therefore, all utilized quota is sold. Harvesters and processors can make as many transactions per day and per season as they want, subject to quota restrictions. Note that while processors do not have processing quota constraints within any of the games, processors are still subject to the overall fleet quota restriction for non-coop games and quota held by harvesters in their cooperative for coop games.

Harvesters could view their quota restriction in the pie chart near the top of their screen. Fleet quotas for TAC games showed overall fleet quota utilization and remaining fleet quota. In individual quota games harvesters only saw their progress towards their harvest quota constraint. Quota gifts increased the unharvested quota available to harvesters in PAQ and PQC games. Processors were able to view fish quota available to them; in games without cooperatives, this was equal to all unharvested fish quota. In PCC and PQC, processors total pie consisted of quota held by harvesters within their cooperative. Harvesters and processors could hover over the pie chart to see actual used and remaining quota numbers.

Participants earn profit from each transaction they make. All participants can view their individual average daily cost curves, as pictured in Figures 1 and 2. By hovering over the graph, they can also view their daily total costs for each unit of production. A vertical line shows participants how many units they have harvested/processed so far that day. To reduce participant frustration for those assigned to be high-cost processors and even out expected session monetary payoffs, processors switch cost functions between Games 2 and 3. All participants could view recent transactions, including the price and number of units traded, and see the profit from each of their transactions. Total profit from the day was presented to each participant at the bottom of the page, not pictured in Figure 1 or 2.

In addition to viewing daily harvesting/processing costs, participants can check their expected profit for each transaction before submission as seen in Figures 1 and 2. Harvesters can check the profit for various prices and numbers of units they specify. Processors can check their hypothetical profit from an offer before they submit it; however, if harvesters do not accept the full amount offered then not all of the profit will be realized. Processors could submit a new offer at any time, which would overwrite their previous offer.

We introduced and explained the experiment to participants using neutral terms. We did not mention the fishery related context at all, instead explaining that participants acting as harvesters would harvest “resources” that processors can turn into “widgets” to sell to a wholesaler. Neutral terminology avoids participant bias from affecting the experiment, allowing participants to instead focus on maximizing their monetary payoff. If the incentives within our experiment model represented real life incentives, then our participants would make the same decision as real-world agents would. Introducing a potentially controversial context such as fisheries could reduce experimental control, so therefore, we chose to present the experiment in a neutral context.

We recruited for experimental sessions at University of Washington undergraduate classes. Students signed up for a time to appear at a meeting location and needed to their own laptop to participate[2]. They were told they would receive a $10 participation fee, with the opportunity to earn “considerably more” during the experiment; pizza was also provided. We designed the experiment to allow exactly 13 participants, so if there were extra participants,

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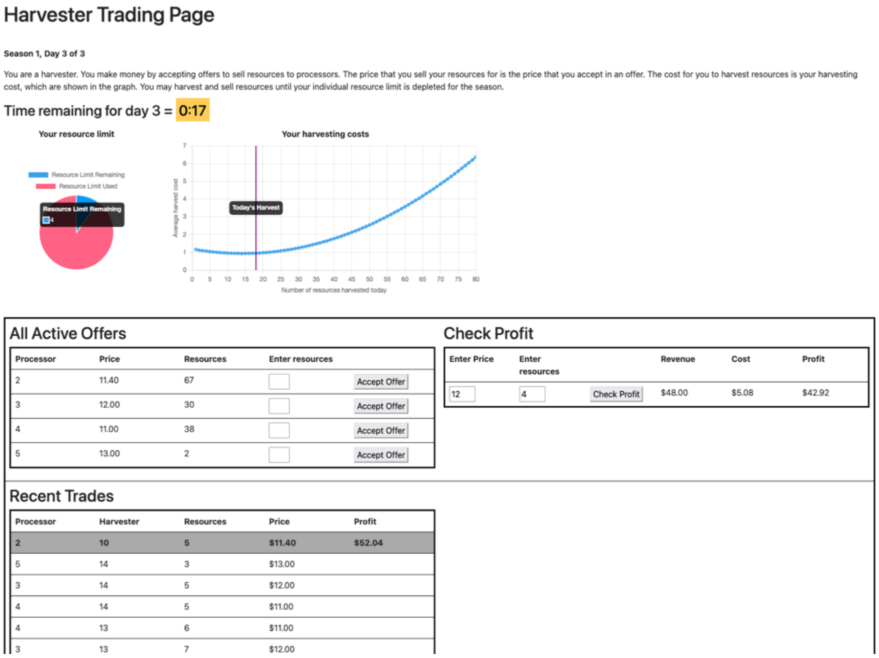
[2] Two spare laptops were available for students that forgot one or only own a tablet. Almost all students at the University of Washington own a laptop.

volunteers, then randomly selected subjects, were paid the participation fee and dismissed. Roles were randomly assigned to participants, and two of the four processors were randomly determined to be low-cost for the first two games and high-cost for the second two games, and vise-versa (the nine harvesters were homogenous). Participants signed a consent form and then read the instructions. After all participants had read the instructions and any questions had been answered, the experiment began. After four games, participant game profit was converted to US dollars and they were paid privately in cash or Venmo, their choice. Total earnings, including the show-up fee, averaged \$49 with a standard deviation of \$7.74[3] for a session lasting approximately two hours.



Harvester Trading Page

Season 1, Day 3 of 3

You are a harvester. You make money by accepting offers to sell resources to processors. The price that you sell your resources for is the price that you accept in an offer. The cost for you to harvest resources is your harvesting cost, which are shown in the graph. You may harvest and sell resources until your individual resource limit is depleted for the season.

Time remaining for day 3 = 0:17

All Active Offers

Processor	Price	Resources	Enter resources	
2	11.40	67		Accept Offer
3	12.00	30		Accept Offer
4	11.00	38		Accept Offer
5	13.00	2		Accept Offer

Check Profit

Enter Price	Enter resources		Revenue	Cost	Profit
12	4	Check Profit	\$48.00	\$5.08	\$42.92

Recent Trades

Processor	Harvester	Resources	Price	Profit
2	10	5	\$11.40	\$52.04
5	14	3	\$13.00	
3	14	5	\$12.00	
4	14	5	\$11.00	
4	13	6	\$11.00	
3	13	7	\$12.00	

Figure 1: Harvester Trading Page

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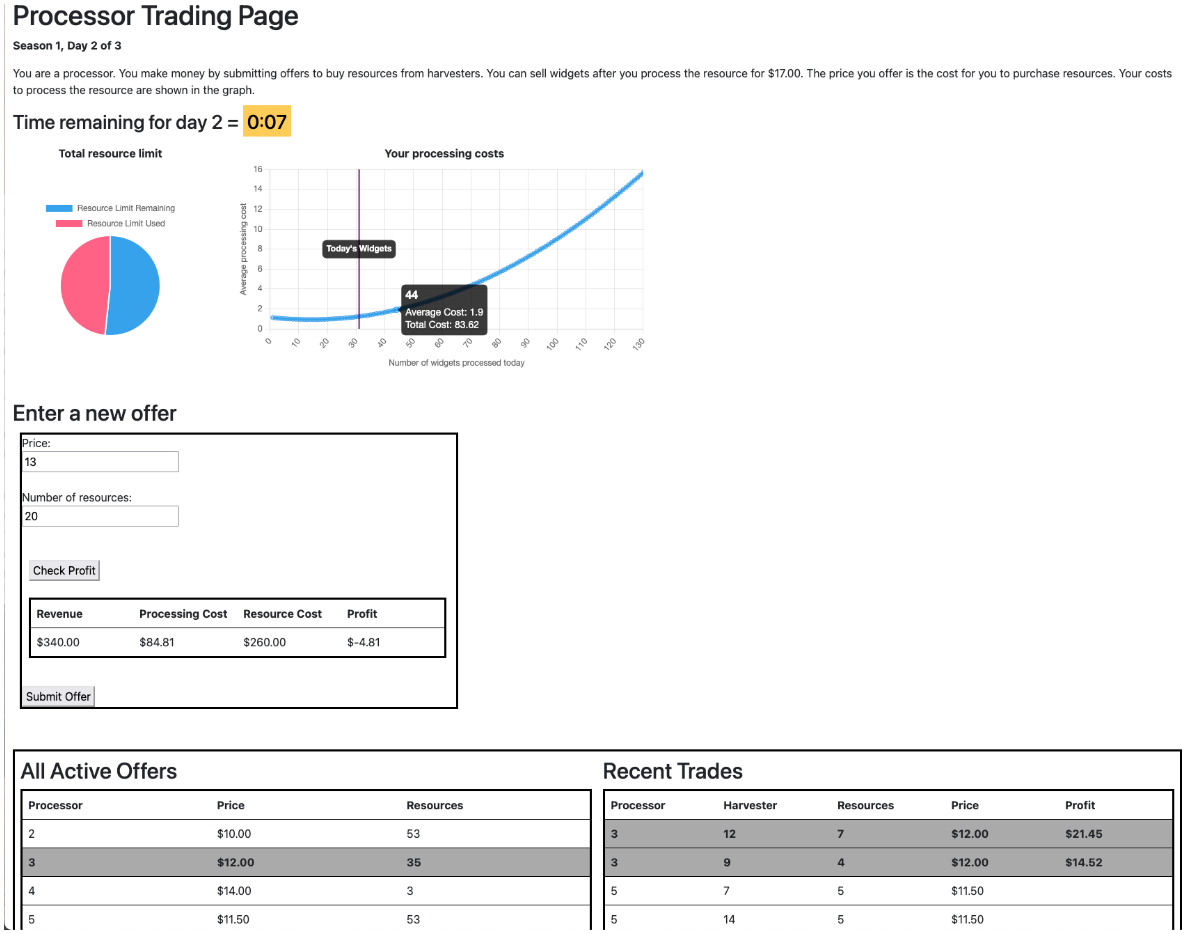
[3] The minimum payment was set at \$30, even if calculated earnings fell below this. The maximum payment awarded was \$65, and the median payment was \$50.



Processor Trading Page

Season 1, Day 2 of 3

You are a processor. You make money by submitting offers to buy resources from harvesters. You can sell widgets after you process the resource for $17.00. The price you offer is the cost for you to purchase resources. Your costs to process the resource are shown in the graph.

Time remaining for day 2 = 0:07

Enter a new offer

Price:
13

Number of resources:
20

Revenue	Processing Cost	Resource Cost	Profit
$340.00	$84.81	$260.00	$-4.81

All Active Offers

Processor	Price	Resources
2	$10.00	53
3	**$12.00**	**35**
4	$14.00	3
5	$11.50	53

Recent Trades

Processor	Harvester	Resources	Price	Profit
3	**12**	**7**	**$12.00**	**$21.45**
3	**9**	**4**	**$12.00**	**$14.52**
5	7	5	$11.50	
5	14	5	$11.50	

Figure 2: Processor Trading Page

4. RESULTS

Figure 3 shows the average total number of units traded per day in each season across the games. The dashed line shows the most efficient harvest level of 120 units per day, which would minimize average variable harvesting costs. As we would expect, a "race-to-fish" or TAC does not yield daily harvest anywhere near optimal levels; most of the fleet quota is harvested on the first day, with zero left for day three. For all of the individual harvest quota games, ITQ, PCC, PAC, and PQC, we expect daily harvest rates at or near the optimal rate of 120 units per day. Each game exhibits some learning in early seasons, with ITQ showing the most learning by far, as the first individual quota game. Typically, most participants raced to fish during the first day of the first season of ITQ, then observed one other subject obtain higher prices for their quota by day three. We do see average daily harvest for the four individual harvest right games converge to very near the optimum line.

While we expect the fleet quota constraint to bind each season of each game, this did not occur in all games. All seasons of all sessions did use the full quota, 360, units in the TAC game. The average total harvest per season was 353 for ITQ, 339 for PCC, 333 for PAQ, and 338 for PQC. The lower harvest in the more complex games that included processor quota and cooperatives seemed to result partially from some participants not understanding how to interact with the more complex mechanisms. Some of the harvest quota inefficiencies, such as that of ITQ, typically seemed to result from harvesters waiting until the last possible second of day three to try to get better payoffs, and not getting their transaction in before the day timer ended. All harvesters were verbally reminded that waiting until the last second could result in transactions not being received at the beginning of the ITQ game, but some harvesters consistently showed this behavior.

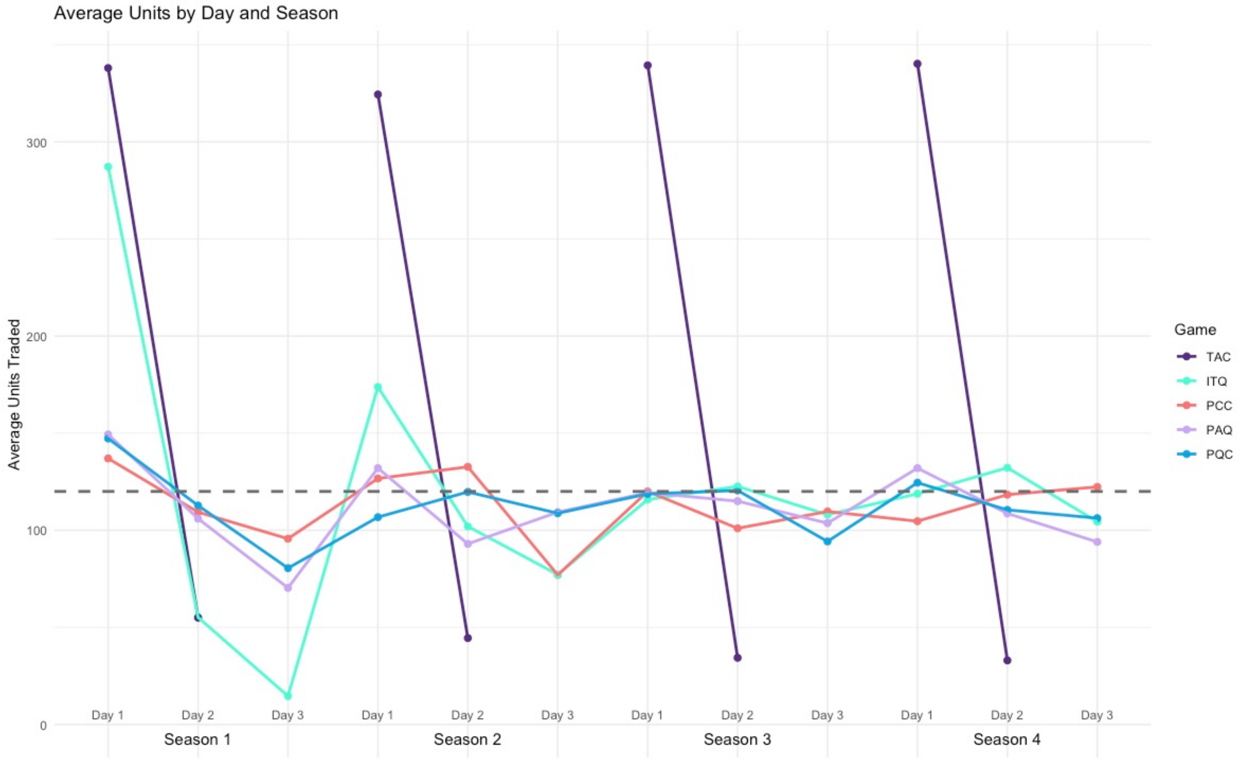


Figure 3: Average units traded per day in each game

Ex-vessel Prices

Market prices, or ex-vessel prices exhibited enormous variation in early seasons of each game due to market mechanisms and a change in the costs and wholesale price due the inflationary value (Ikica et al., 2023). Figure 4 shows a time series of prices in each game played in session four. Price variation is clearly largest in early seasons, and typically much lower by season four. In most sessions, prices were typically lower in early seasons of each game, and then slowly rose. Prices were typically lower for early trades each day of each season and rose throughout the day. Prices converged much most slowly in ITQ than for other games due to the amount of learning in the first individual quota game; as seen in Figure 4, it is not clear prices have fully converged by season 4 in the ITQ game.

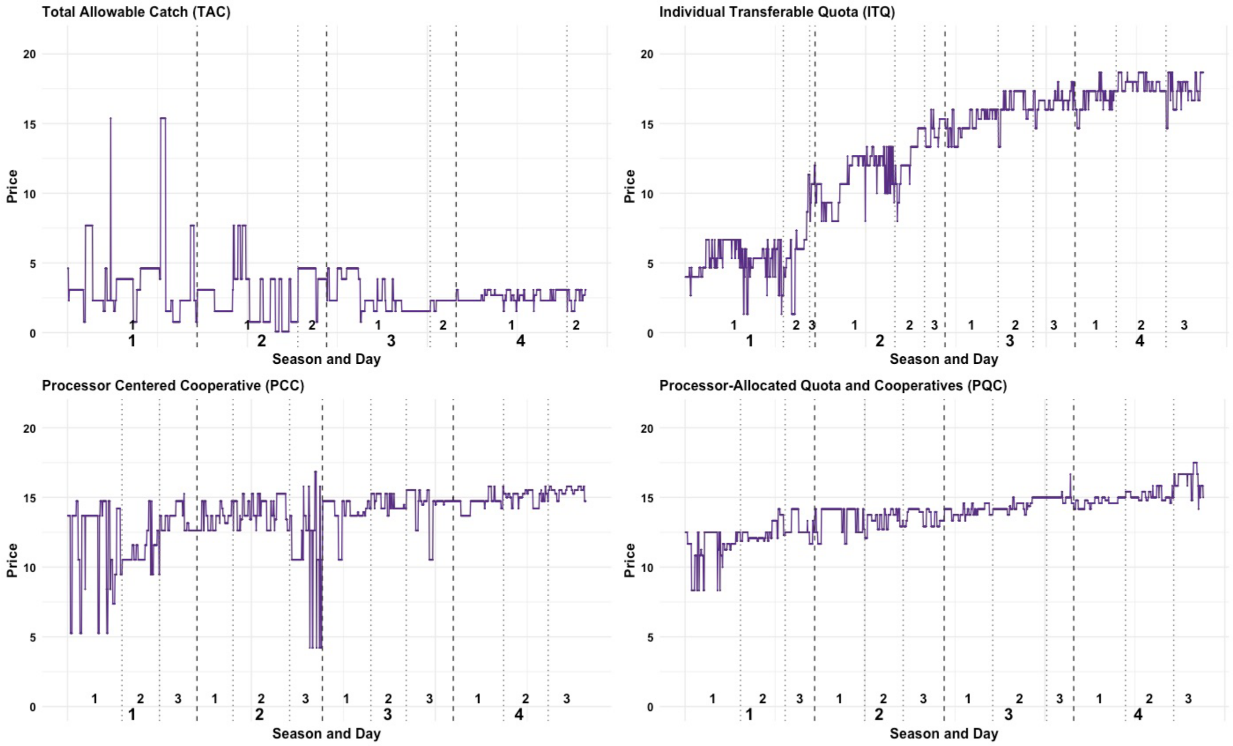


Figure 4: Price Convergence in Session 4

To account for continued price convergence, we estimated a simple dynamic convergency model (Myagkov and Plott, 1997) where t is the season, and each game g price p is assumed to converge to a common asymptote, β_{g2}:

$$P_{itg} = \sum_g \left[\beta_{g11} D_1 \left(\frac{1}{t}\right) + \cdots + \beta_{g1K} D_K \left(\frac{1}{t}\right) + \beta_{g2} \left(\frac{t-1}{t}\right)\right] + \beta_{3j} X_{ij} + U_k + U_{kp} + \epsilon_{it}.$$

A coefficient for each session k and a dummy variable D_k that equals 1 for session k capture session and game level convergence. We include additional explanatory fixed effects, and random effects for both the sessions, and at the participant level, p for both the buyer and the seller.

The results from our convergence model and a naïve model without convergence are presented in Table 3. We compare multiple model specifications to assess the robustness of our results. Model 1 estimates a convergence model with random effects for the session and participant. Both Model 2, Model 3, and Model 4 include heteroskedasticity-robust participant clustered standard errors, with Model 2 also including session fixed effects. Model 4 is a more restricted model that does not include estimates for game days, the wholesale price, or whether the processor was a high-cost processor. The naïve model, Model 5, does not estimate a convergence model, instead simple estimating each coefficient using only seasons 3 and 4 of each game.

As all games included four seasons, we must consider the impact of a finite, known, end season on cooperative game results. With the exception of one session, participants were not paying close attention to which season it was, and we did not see large changes in prices offered by processors during season four for the PCC or PQC games compared to season three. Session five, however, included a vocal participant; one participant announced that it was season four, and so processors could offer low prices to harvesters in their cooperative after the season began. The average price of season four was \$6.97 compared to an average price of \$16.19 for season three during session five[4]. Therefore, all reported results exclude season four of the PCC game for session five; session five did not play PQC. We did include season four of all other cooperative game sessions.

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[4] Price changes between season 3 and 4 for cooperative games for other session were as follows: session 1 14.52 to 13.92; session 2 16.67 to 16.03; session 3 16.63 to 16.29 and 15.21 to 14.13; session 4 14.31 to 15.00 and 14.39 to 15.23.

The asymptote coefficients for each game, the game price coefficients, are all statistically significant at the 0.1% level for all games. While the game coefficients in each model vary by one to two dollars between models, the ranking of game prices between all models is identical, other than for the naïve model, which includes a much lower ITQ price. For all convergence models, the prices of all individual quota games are much larger than the TAC game; among individual quota games, ITQ prices are the highest, as expected. PQC prices are the lowest, which is also expected as PQC combines the mechanism of the other two games, and PAQ prices appear slightly higher than PCC prices in all models.

As the ranking of coefficients in all models is similar, we prefer and will interpret Model 2, as it includes session fixed effects and participant cluster robust standard errors. The differences between game asymptote coefficients are statistically significant at the 0.1% level, other than for the PAQ and PCC games, which are not statistically different. TAC game estimates are very similar to the theoretical market price of $5, even for the naïve model, indicating that prices converged very well in the TAC game. ITQ prices are very high, and in the case of Model 2, very close to the wholesale price of $20. Considering that the minimum average variable processing cost is $1.03 (for a low-cost processor), we believe that the convergence model may slightly exaggerate ITQ prices due to the large difference between convergence time in the ITQ game versus for other games. This potential overestimation of ITQ prices means that effects we estimate between ITQ and the other individual quota games are upper boundaries on true impacts. Coefficients for the other individual quota games are significantly different than ITQ, though still much higher than for TAC.

The day has a small but significant effect on the prices, with the price going up across days. High-cost processors do not offer a statistically different price with robust standard errors, and the difference in Model 1 is small, less than $0.20. Price differences due to the wholesale price, or the difference between the wholesale price from the previous game (both due to the randomly drawn inflationary value) are very small, less than $0.10, and only significant for the difference coefficient at the 5% level. Session fixed effects are significant for two of the sessions, as compared to the omitted session five.

Table 3: Ex-vessel prices for all games

		Random effects for session and player	Random effects for session only	No Random effects	Smaller model	Naïve season 3&4
Asymptotes	TAC	5.4*** (0.58)	5.63*** (0.6)	4.94*** (0.47)	4*** (0.05)	3.52*** (0.42)
	ITQ	19.92*** (0.57)	19.94*** (0.59)	19.25*** (0.46)	19.19*** (0.05)	13.82*** (0.42)
	PCC	16.92*** (0.55)	17.3*** (0.56)	16.7*** (0.44)	16.55*** (0.07)	14.15*** (0.39)
	PAQ	17.52*** (0.59)	17.62*** (0.61)	17.4*** (0.45)	17.78*** (0.07)	14.67*** (0.4)
	PQC	16.92*** (0.55)	16.98*** (0.57)	16.09*** (0.44)	15.65*** (0.06)	13.97*** (0.39)
High-Cost Processor		-0.17*** (0.03)	-0.17*** (0.03)	-0.18*** (0.03)		-0.24*** (0.03)
Day (1-3)		0.68*** (0.02)	0.74*** (0.02)	0.73*** (0.02)		0.3*** (0.02)
Wholesale Price (10-40)		-0.044*** (0.0074)	-0.037*** (0.0075)	0.001 (0.0049)		0 (0)
Wholesale Price Difference		-0.069*** (0.0087)	-0.072*** (0.009)	-0.064*** (0.0059)		-0.1*** (0)
Season Units Sold		-0.0026* (0.0012)	-0.0038** (0.0013)	-0.0046*** (0.0012)		0** (0)
Total Allowable	TAC Session 1	9.02*** (0.58)	9.13*** (0.6)	9.5*** (0.45)	8.51*** (0.1)	

Catch (TAC)	TAC Session 2	8.51*** (0.61)	8.69*** (0.63)	6.81*** (0.47)	5.97*** (0.1)
	TAC Session 3	6.53*** (0.61)	7.1*** (0.62)	6.2*** (0.51)	5.21*** (0.1)
	TAC Session 4	4.62*** (0.58)	5.19*** (0.6)	3.68*** (0.47)	2.82*** (0.1)
	TAC Session 5	10.03*** (0.6)	10.36*** (0.61)	10.85*** (0.47)	9.86*** (0.1)
Individual Transferable Quota (ITQ)	ITQ Session 1	7.35*** (0.58)	7.67*** (0.6)	7.17*** (0.47)	5.21*** (0.1)
	ITQ Session 2	8.27*** (0.59)	8.46*** (0.61)	6.43*** (0.45)	5.48*** (0.1)
	ITQ Session 3	6.79*** (0.6)	7.1*** (0.62)	6.48*** (0.51)	6.06*** (0.1)
	ITQ Session 4	6.18*** (0.59)	6.5*** (0.61)	5.74*** (0.48)	5.94*** (0.1)
	ITQ Session 5	8.92*** (0.6)	8.68*** (0.62)	9.11*** (0.48)	8.22*** (0.1)
Processor Centered Cooperative (PCC)	PCC Session 3	15.02*** (0.55)	15.15*** (0.57)	14.93*** (0.45)	15.58*** (0.11)
	PCC Session 4	13.34*** (0.55)	13.52*** (0.57)	12.31*** (0.46)	11.52*** (0.1)
	PCC Session 5	11.26*** (0.6)	11.08*** (0.62)	11.01*** (0.48)	10.06*** (0.1)
Processor Allocated Quota (PAQ)	PAQ Session 1	14.87*** (0.59)	15.31*** (0.61)	15.05*** (0.44)	15.16*** (0.1)
	PAQ Session 2	15.76*** (0.56)	15.92*** (0.58)	14.37*** (0.41)	14.95*** (0.11)
	PAQ Session 5	14.68*** (0.6)	14.62*** (0.62)	15.57*** (0.48)	15.75*** (0.1)
Processor Allocated Quota and Cooperative (PQC)	PQC Session 1	15.6*** (0.6)	15.57*** (0.62)	14.91*** (0.47)	13.77*** (0.1)
	PQC Session 2	16.16*** (0.54)	16.43*** (0.55)	15.44*** (0.4)	16*** (0.1)
	PQC Session 3	14.37*** (0.54)	14.4*** (0.56)	13.84*** (0.46)	13.03*** (0.1)
	PQC Session 4	14.09*** (0.57)	14.27*** (0.59)	12.92*** (0.48)	12.08*** (0.1)

Adj R-squared	0.8717	0.8464	0.9746	0.9729	0.981
AIC	113045	116832	117132	118906	55600

Note: ***, **, and * indicate p-value <0.001, <0.01, and <0.05 respectively.
Standard errors are clustered for each harvester and processor and computed using the sandwich estimator.

Profit

Market efficiency within each game is determined by daily harvesting and processing rates, processing sector low-cost market share, firm consolidation, and quota utilization. TAC should result in lower total industry profit, a measure of market efficiency, due to very high daily harvest rates[5]. All individual quota games are expected to yield larger total industry profit, with exact overall industry profit depending upon individual firm harvesting and processing rates and costs. Total estimated industry profit also varies between games due to a lack of full quota utilization in some games, particularly PCC, PAQ, and PQC. To ensure our results are robust to quota utilization, we present profit estimates per total unit traded in addition to total profit estimates.

Table 4 presents total industry profit converged estimates; Table A1 contains the full model with all coefficients. Breusch-Pagan testing failed to reject the null hypothesis of homoskedasticity ($p<0.493$). As expected, industry efficiency both per unit and total profit are smaller in TAC than for all individual quota games, with the difference between TAC and ITQ ($p<0.001$) and TAC and PQC (0.048) being statistically significant. ITQ had the largest total profit before and after accounting for quota utilization, most likely due to competition between processors and even distribution of harvest quota encouraging low harvest and processing costs. PAQ total profit is lowest among individual quota games, and is not statistically different from TAC ($p<0.717$). Some processors had difficult utilizing processor quota gifting, and gifted all 18

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[5] 8/20 TAC game seasons harvested the entire 360 units within one day, and the remaining 12/20 harvested less than 100 units on day 2.

of their units to one harvester each season. Harvesters receiving 18 units of quota harvested 50 total quota units, substantially increasing average harvesting costs. Total profit in cooperative games was not statistically different from TAC in the case of PCC (p<0.221), though was larger than for PAQ. The combined game resulted in the largest total profit among PCC, PAQ, and PQC, which is interesting as the combined game introduced two mechanisms that could reduce efficiency if participants struggled. Total profit per unit of quota utilized were ranked the same as total profit, indicating that these results are driven by cost differences and not simply quota utilization.

Table 4: Market Efficiency

		Total Profit	Total Profit Per Unit
Asymptotes		5341.6***	14.84***
	TAC	(710)	(2.05)
		8691.3***	24.92***
	ITQ	(677.9)	(4.96)
		6808.3***	20.86***
	PCC	(947.8)	(2.74)
		5752***	16.96***
	PAQ	(875.2)	(2.53)
		7448.1***	22.12***
	PQC	(757.9)	(2.19)

Adj R-squared	0.9547	0.9551
AIC	1381.8	469.7

Note: ***, **, and * indicate p-value <0.001, <0.01, and <0.05 respectively.

We estimate welfare impacts for individual firm types by considering the harvesting and processing sectors, and low- and high-cost processing plants within the processing sector. We use a convergence model to estimate profit for each player type in separate regressions for each game, similar to our price estimation strategy. As with game prices, we estimated heteroskedasticity-robust clustered standard errors. Table 5 includes converged profit coefficients for all harvesters, all processors, low-cost processors only, and high-cost processors only. All models estimate participant clustered robust standard errors. The full model including all coefficients is in Appendix table A2. The number of observations for profit is much smaller than for prices, only one per player per game day; hence, standard errors are much larger than for price estimates. Due to the smaller number of estimates, adding random and fixed effects for sessions and participants further increased standard errors; therefore, we include the results only from a model without random and fixed effects.

All game coefficients estimate total profit without fixed costs, or quasi-rents. As expected, quota rationalization from a TAC to an ITQ results in a large shift of profit from the processing sector to the harvesting sector. Harvester and processor profits are statistically different for both TAC ($p<0.000$) and ITQ ($p<0.021$). TAC profits for all player types are very similar to theoretical fixed costs of \$117, \$1066, and \$692 for harvesters, low-cost, and high-cost processors, respectively. Risk of processing plant shutdown or closure from rationalization can be clearly seen in the much lower quasi-rents in ITQ compared to processing plant fixed costs. The addition of processor quota or cooperatives all transfer some rent back to the processing sector. Overall processing sector quasi-rents are not statistically different than harvester quasi-rents for PCC (p<0.825), PAQ (p<0.887), or PQC (p<0.103).

While PAQ, PCC, and PQC all help the processing sector overall, the gains are not identical between high- and low-cost processors. Low-cost processors do not see statistically significant gains from PCC (p<0.512), PAQ (p<0.876), or PQC (p<0.327). High-cost processors only see gains from a combination of both processor quota and cooperatives, PQC (p<0.094). In fact, high-cost processors actually do slightly worse from PCC (p<0.950) or PAQ (p<0.843) alone, though the difference is very small and not statistically significant. While processor quota and, especially, cooperatives may help large, low-cost, industrial processing plants, our results indicate that these policies must be combined to improve high-cost processing plant quasi-rents. Fortunately, gains for high-cost processing plants of combining these policies are substantial, and transfers from the harvesting sector do not closely approach TAC levels of profit (p<0.000).

We estimate converged profit per utilized total fleet quota for each player type and game, included in Table 6, to ensure our results are driven by true difference in profit between games and player types, instead of by changes in quota utilization. Table A3 contains the full model including all coefficients. The results clearly indicate that while processor quota and cooperatives both may assist low-cost processing plants, only PQC assists high-cost processing plants. Managers concerned about high-cost, often rural, processing plants that provide important jobs should consider combining these two policies.

Table 5: Total Profit by Firm Type

	Harvester	Processor	Low-Cost	High-Cost

TAC	87.85** (32.41)	812.5*** (95.75)	1015.58*** (192.2)	587.67*** (70.11)
ITQ	358.72*** (19.49)	255.11*** (31.29)	308.61** (86.78)	207.09** (53.63)
PAQ	249.11*** (20.52)	256.8*** (24.01)	324.08** (76.55)	195** (46.25)
PCC	274.62*** (21.2)	287.43*** (32.55)	377.29** (89.54)	203.05** (53.73)
PQC	270.56*** (22.54)	349.87*** (36.16)	398.19*** (82.39)	301.21*** (55.45)
Day (1-3)	-22.19** (8.18)	-119.05*** (11.82)	-153.38*** (38.35)	-87.46** (22.89)
Adj R-Squared	0.648	0.596	0.615	0.627
AIC	23681	11559	6048	5641

Note: ***, **, and * indicate p-value <0.001, <0.01, and <0.05 respectively.
Standard errors are clustered for each individual and computed using the sandwich estimator.

Table 6: Per-Unit Profit for each Firm Type

	Harvester	Processor	Low-Cost	High-Cost
TAC	0.25** (0.09)	2.26*** (0.27)	2.83*** (0.53)	1.64*** (0.2)

ITQ	1.02***	0.74***	0.88**	0.6**
	(0.06)	(0.09)	(0.24)	(0.15)
PAQ	0.73***	0.72***	0.91**	0.55**
	(0.06)	(0.07)	(0.21)	(0.13)
PCC	0.83***	0.82***	1.08**	0.58**
	(0.07)	(0.09)	(0.25)	(0.15)
PQC	0.8***	1***	1.14***	0.87***
	(0.07)	(0.1)	(0.23)	(0.16)
Day (1-3)	-0.06*	-0.34***	-0.43***	-0.25**
	(0.02)	(0.03)	(0.11)	(0.06)
Adj R-Squared	0.653	0.597	0.615	0.628
AIC	2016	1869	1131	727

Note: ***, **, and * indicate p-value <0.001, <0.01, and <0.05 respectively.
Standard errors are clustered for each individual and computed using the sandwich estimator.

Units

To further explain why profit varies between high- and low-cost processors between games, we estimated daily processing amounts for each processing plant cost-type divided by the total number of units processed in the season using a convergence model for each game and processor type. Table 7 shows these converged estimates, which can be interpreted as the share of the total season quota a processor is estimated to process each of the three days of the season; Table A4 includes the full model. Total daily processing sums for all individual quota games are 0.272 or 0.271, which indicates that differences in processing shares result from splits between high- and low-cost processing plants, not from gains in industry efficiency between these games. As expected, daily processing rates for individual processor types and for the processing industry are highest for the "race-to-fish" or TAC game.

While individual harvest quota games all yield lower shares of daily processing rates due to season lengthening, important differences between high- and low-cost processors exist. High-cost processors actually process a smaller share of the total quota for both PCC and PAQ, as compared to an ITQ game alone. Although none of the differences are statistically significant, cooperatives alone do appear to result in lower market share for high-cost processors. The combined game, PQC, does increase the market share obtained by high-cost processors, and in fact, market shares appear larger than for low-cost processors. These results may be over approximations; however, they do explain why high-cost processors only receive gains from both cooperatives and processor quota as compared to individual harvest quota alone.

Table 7: Number of Units Processed by Processing Firm Type

	Low-Cost Units	High-Cost Units
TAC	0.25*** (0.05)	0.16*** (0.03)
ITQ	0.15*** (0.02)	0.12*** (0.01)
PQ	0.15*** (0.02)	0.12*** (0.02)

C	0.16**	0.11***
	(0.03)	(0.02)
PQC	0.13***	0.14***
	(0.02)	(0.01)
S	-0.03**	-0.02***
	(0.01)	(0)
Adj R-Squared	.655	.703
AIC	-875	-1220

Note: ***, **, and * indicate p-value <0.001, <0.01, and <0.05 respectively.
Standard errors are clustered for each individual and computed using the sandwich estimator.

5. CONCLUSION

Although fisheries rationalization offers many attractive outcomes for some harvesters and managers, research studies historically ignored social outcomes, including processing sector outcomes. The lack of research attention to processing plant outcomes is even more true for high-cost processing firms. Recent processing plant closures across the West Coast have impacted rural communities that rely on processing plant jobs and revenue. In an attempt to protect the processing sector and meet other management goals, processor-allocated quota and processor centered cooperatives have been instituted individually and together in several large fisheries across the West Coast and Alaska.

Processor-allocated quota and processor centered cooperatives each alone help protect the processing sector overall, reducing the total rent transfer from the processing sector to the harvesting sector from fisheries rationalization. A combination of the two policies transfers additional rent, though rent splitting does not approach “race-to-fish” levels of rent for harvesters or processors. These policies differentially impact high- and low-cost processing firms; while processor-allocated quota and processor centered cooperatives assist low-cost processing plants in profitability, only a combination of the two policies transfers rent to high-cost processing plants. As high-cost, often rural, processing plants are often of particular importance to managers due to local jobs and community priorities, these results yield important lessons about the differential impact of the policies.

In addition to yielding important information about rent splitting between the harvesting and processing sectors and within the processing sector after fisheries rationalization, our experiment provides a template for additional research on fisheries rationalization institutions. We tested only a few of many possible rationalization institutions, such as “two-pie” versus “one-pie” splits of processor quota, processor centered cooperatives with penalty years versus without penalty years between changing processors, and allowing for some level of vertical integration. We suggest future research continue to test these scenarios, as many of these policies may have various effects that can be differential when applied to different firm types, as we showed.

Appendix

Table A1: Full Efficiency Model Results

		Total Profit	Total Profit Per Unit
Total Allowable Catch (TAC)	TAC Asymptote	5341.57*** (710.05)	14.84*** (2.05)
	TAC Session 1	2325.64. (1282.06)	6.46. (3.7)
	TAC Session 2	4440.21** (1282.06)	12.33** (3.7)
	TAC Session 3	7598.02*** (1282.06)	21.11*** (3.7)
	TAC Session 4	2723.51* (1282.06)	7.57* (3.7)
	TAC Session 5	2828.06* (1290.96)	7.86* (3.73)
Individual Transferable Quota (ITQ)	ITQ Asymptote	8691.3*** (677.92)	24.92*** (1.96)
	ITQ Session 1	8513.1*** (1278.32)	23.78*** (3.69)
	ITQ Session 2	6517.8*** (1278.32)	19.41*** (3.69)
	ITQ Session 3	9961.75*** (1278.32)	27.77*** (3.69)
	ITQ Session 4	2139.17 (1278.32)	5.61 (3.69)
	ITQ Session 5	7406.44*** (1278.32)	20.32*** (3.69)
Processor Allocated Quota (PQ)	PQ Asymptote	5752.03*** (875.19)	16.96*** (2.53)
	PQ Session 1	8083.64*** (1303.8)	25.4*** (3.77)
	PQ Session 2	4001.62** (1303.8)	13.45*** (3.77)
	PQ Session 5	4414.95** (1303.8)	12.03** (3.77)

Processor Centered Cooperative (C)	C Asymptote	6808.32***	20.86***
		(947.83)	(2.74)
	C Session 3	7011.8***	22.26***
		(1314.66)	(3.8)
	C Session 4	4898.49***	13.27***
		(1314.66)	(3.8)
	C Session 5	10287.23***	29.32***
		(1309.21)	(3.78)
Processor Allocated Quota and Cooperatives (PQC)	PQC Asymptote	7448.15***	22.12***
		(757.94)	(2.19)
	PQC Session 1	11908.66***	35.01***
		(1287.93)	(3.72)
	PQC Session 2	1336.72	4.79
		(1287.93)	(3.72)
	PQC Session 3	9579.95***	28.68***
		(1287.93)	(3.72)
	PQC Session 4	7308.36***	19.64***
		(1287.93)	(3.72)
Adj R-squared		0.955	0.955
AIC		1382	470

Note: ***, **, and * indicate p-value <0.001, <0.01, and <0.05 respectively.

Table A2: Profit by Firm Type

		Harvester	Processor	Low Cost	High Cost
Total Allowable Catch (TAC)	TAC Asymptote	87.85**	812.5***	1015.58***	587.67***
		(32.41)	(95.75)	(192.2)	(70.11)
	TAC Session 1	102.37**	386.32.	560.03	225.23
		(23.62)	(133.05)	(121.94)	(198.13)
	TAC Session 2	56.91.	731.81**	850.48.	732.17
		(30.43)	(102.88)	(153.62)	(183.29)
	TAC Session 3	30.57	1539.27**	1867.25*	1233.15*
		(145.85)	(248.05)	(183.56)	(122.29)
	TAC Session 4	-36.37	960.65*	1660.67*	428.08*
		(69.79)	(310.19)	(208.21)	(53.45)

	TAC Session 5	239.15** (70.81)	509.37 (390.67)	195.04 (657.91)	640.57 (358.98)
Individual Transferable Quota (ITQ)	ITQ Asymptote	358.72*** (19.49)	255.11*** (31.29)	308.61** (86.78)	207.09** (53.63)
	ITQ Session 1	141.98*** (18.92)	727.92** (122.56)	928.35. (220.49)	532.97. (85.06)
	ITQ Session 2	111.21*** (17.69)	630.87** (78.99)	806.43* (77.22)	460.8. (96.04)
	ITQ Session 3	177.78*** (25.94)	768.1** (98.96)	987.4* (90.47)	554.29. (92.73)
	ITQ Session 4	25.3 (17.1)	459.3** (83.62)	662.73* (76.06)	261.37. (49.87)
	ITQ Session 5	167.91*** (19.79)	577.37** (99.06)	761.26. (153.96)	398.97 (114.64)
Processor Allocated Quota (PQ)	PQ Asymptote	249.11*** (20.52)	256.8*** (24.01)	324.08** (76.55)	195** (46.25)
	PQ Session 1	287.31*** (21.36)	365.14*** (28.09)	458.55. (82.47)	277.21. (50.54)
	PQ Session 2	161.35*** (18.25)	308.39*** (30.92)	396.59. (87.32)	225.69. (45.7)
	PQ Session 5	182.69*** (19.59)	294.81*** (24.6)	371.97. (77.96)	223.13. (45.61)
Processor Centered Cooperative (C)	C Asymptote	274.62*** (21.2)	287.43*** (32.55)	377.29** (89.54)	203.05** (53.73)
	C Session 3	255.63*** (23.4)	347.11*** (32.84)	392.78. (82.34)	306.93. (50.41)
	C Session 4	152.65*** (18.2)	402.7*** (38.72)	442.24. (95.44)	368.65* (49)
	C Session 5	260.94*** (18.62)	608.12** (104.51)	605.39 (208.8)	616.33. (100.13)
Processor Allocated Quota and Cooperatives (PQC)	PQC Asymptote	270.56*** (22.54)	349.87*** (36.16)	398.19*** (82.39)	301.21*** (55.45)
	PQC Session 1	375.82*** (25.18)	484.74*** (56.55)	517.34. (88.66)	460.34. (104.28)
	PQC Session 2	91.61*** (19.74)	243.22*** (25.4)	333.74. (80.33)	160.91 (50.78)
	PQC Session 3	295.94*** (18.43)	470.41** (67.78)	544.41. (135.8)	404.61 (115.96)

	PQC Session 4	217.56*** (19.52)	457.46*** (37.64)	579.51* (86.38)	337.47. (55.91)
Day (1-3)		-22.19** (8.18)	-119.05*** (11.82)	-153.38*** (38.35)	-87.46** (22.89)
Adj R-squared		0.648	0.596	0.615	0.627
AIC		23681	11559	6048	5641

Note: ***, **, and * indicate p-value <0.001, <0.01, and <0.05 respectively.
Standard errors are clustered for each individual and computed using the sandwich estimator.

Table A3: Profit Per Unit by Type

		Harvester	Processor	Low Cost	High Cost
Total Allowable Catch (TAC)	TAC Asymptote	0.25** (0.09)	2.26*** (0.27)	2.83*** (0.53)	1.64*** (0.2)
	TAC Session 1	0.29** (0.07)	1.08. (0.37)	1.56 (0.34)	0.63 (0.55)
	TAC Session 2	0.16. (0.09)	2.04** (0.29)	2.37. (0.43)	2.04 (0.51)
	TAC Session 3	0.09 (0.41)	4.28** (0.69)	5.19* (0.51)	3.43* (0.34)
	TAC Session 4	-0.1 (0.19)	2.68* (0.86)	4.62* (0.58)	1.19* (0.15)
	TAC Session 5	0.67** (0.2)	1.42 (1.09)	0.55 (1.83)	1.78 (1)
Individual Transferable Quota (ITQ)	ITQ Asymptote	1.02*** (0.06)	0.74*** (0.09)	0.88** (0.24)	0.6** (0.15)
	ITQ Session 1	0.4*** (0.05)	2.03** (0.34)	2.59. (0.61)	1.49. (0.24)
	ITQ Session 2	0.33*** (0.05)	1.82** (0.23)	2.32* (0.21)	1.33. (0.28)
	ITQ Session 3	0.5*** (0.07)	2.15** (0.28)	2.76* (0.25)	1.55. (0.26)
	ITQ Session 4	0.06 (0.05)	1.28** (0.23)	1.84* (0.21)	0.73. (0.14)

	ITQ Session 5	0.46***	1.61**	2.12.	1.11
		(0.06)	(0.28)	(0.43)	(0.32)
Processor Allocated Quota (PQ)	PQ Asymptote	0.73***	0.72***	0.91**	0.55**
		(0.06)	(0.07)	(0.21)	(0.13)
	PQ Session 1	0.89***	1.07***	1.34.	0.81.
		(0.06)	(0.08)	(0.23)	(0.14)
	PQ Session 2	0.52***	0.91***	1.16.	0.67.
		(0.05)	(0.09)	(0.25)	(0.13)
	PQ Session 5	0.5***	0.83***	1.05.	0.63.
		(0.06)	(0.07)	(0.22)	(0.13)
Processor Centered Cooperative (C)	C Asymptote	0.83***	0.82***	1.08**	0.58**
		(0.07)	(0.09)	(0.25)	(0.15)
	C Session 3	0.8***	1.02***	1.14.	0.91*
		(0.07)	(0.1)	(0.23)	(0.14)
	C Session 4	0.41***	1.13***	1.24.	1.04*
		(0.05)	(0.11)	(0.27)	(0.14)
	C Session 5	0.75***	1.71**	1.71	1.74.
		(0.06)	(0.29)	(0.58)	(0.27)
Processor Allocated Quota and Cooperatives (PQC)	PQC Asymptote	0.8***	1***	1.14***	0.87***
		(0.07)	(0.1)	(0.23)	(0.16)
	PQC Session 1	1.1***	1.4***	1.48.	1.33.
		(0.07)	(0.16)	(0.25)	(0.3)
	PQC Session 2	0.29***	0.7***	0.95.	0.46
		(0.06)	(0.07)	(0.23)	(0.15)
	PQC Session 3	0.88***	1.36**	1.57.	1.18
		(0.05)	(0.2)	(0.39)	(0.34)
	PQC Session 4	0.59***	1.27***	1.61*	0.94.
		(0.06)	(0.1)	(0.24)	(0.16)
Day (1-3)		-0.06*	-0.34***	-0.43***	-0.25**
		(0.02)	(0.03)	(0.11)	(0.06)
Adj R-squared		0.653	0.597	0.615	0.628
AIC		2016	1869	1131	727

Note: ***, **, and * indicate p-value <0.001, <0.01, and <0.05 respectively.
Standard errors are clustered for each individual and computed using the sandwich estimator.

Table A4: Processed Units by Processor Type

		Low-Cost Units	High-Cost Units
Total Allowable Catch (TAC)	TAC Asymptote	0.21*** (0.03)	0.15*** (0.02)
	TAC Session 1	0.22. (0.03)	0.16. (0.03)
	TAC Session 2	0.16. (0.03)	0.16 (0.06)
	TAC Session 3	0.26. (0.06)	0.18* (0.02)
	TAC Session 4	0.38 (0.09)	0.06 (0.03)
	TAC Session 5	0.49 (0.1)	0.16 (0.08)
Individual Transferable Quota (ITQ)	ITQ Asymptote	0.16*** (0.02)	0.13*** (0.01)
	ITQ Session 1	0.16 (0.05)	0.12* (0.02)
	ITQ Session 2	0.18* (0.02)	0.1. (0.02)
	ITQ Session 3	0.19* (0.02)	0.09* (0.01)
	ITQ Session 4	0.22* (0.02)	0.06. (0.01)
	ITQ Session 5	0.18 (0.06)	0.1 (0.03)
Processor Allocated Quota (PQ)	PQ Asymptote	0.16*** (0.02)	0.12*** (0.02)
	PQ Session 1	0.18. (0.05)	0.1 (0.03)
	PQ Session 2	0.16. (0.04)	0.13. (0.03)
	PQ Session 5	0.15. (0.03)	0.13. (0.02)
Processor Centered Cooperative (C)	C Asymptote	0.17*** (0.03)	0.11*** (0.02)
	C Session 3	0.15. (0.03)	0.13. (0.02)

	C Session 4	0.11. (0.03)	0.17* (0.02)
	C Session 5	0.14. (0.03)	0.14 (0.04)
Processor Allocated Quota and Cooperatives (PQC)	PQC Asymptote	0.14*** (0.02)	0.14*** (0.01)
	PQC Session 1	0.16. (0.03)	0.13* (0.01)
	PQC Session 2	0.16 (0.06)	0.12 (0.05)
	PQC Session 3	0.14. (0.03)	0.14. (0.03)
	PQC Session 4	0.16. (0.03)	0.12* (0.01)
Day (1-3)		-0.03*** (0.01)	-0.02*** (0)
Adj R-squared		0.739	0.72
AIC		-990	-1244

Note: ***, **, and * indicate p-value <0.001, <0.01, and <0.05 respectively.
Standard errors are clustered for each individual and computed using the sandwich estimator.

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