A Safer Catch? The Role of Fisheries Management in Fishing Safety

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ABSTRACT

Commercial fishers are constantly exposed to many risk factors, making it a dangerous occupation. Fisheries management that limits access and catches can give rise to well-known stock and rule-of-capture externalities known as the "race to fish." This market failure dissipates rents and can lead fishers to take on additional risks such as fishing in poor weather, overloading vessels, or delaying maintenance to outcompete others. Rights-based management is expected to reduce the incentives to take on additional risk. Using a large dataset of fishers from around the United States, we empirically estimate the effects of individual fishing quota (IFQ) programs on one important risk factor: the decision to fish in poor weather. We find that risk-taking behavior generally decreases under IFQs, but the magnitude of the shift differs by fishery, and we explore potential drivers of these differences.

Key words: Fisheries management, individual fishing quotas, risk, safety.
JEL codes: I18, J28, Q22, Q28.

INTRODUCTION

Exposure to mortality risk is a defining characteristic of commercial fishing. Open water, unstable surfaces, harsh weather conditions, heavy equipment, shift work, and limited access to emergency medical services typify the working conditions on even the safest commercial fishing vessel. US fatality rates for fishing are about 30 times higher than the occupational fatality rate for all industries (US Bureau of Labor Statistics, 1993–2017 average). Despite the risks, fishers experience high levels of job satisfaction and derive a sense of personal and community identity from fishing (C. L. Smith 1981; Apostle, Kasdan, and Hanson 1985; Pollnac and Poggie 2008; Holland, Abbott, and Norman 2020). Fishers are often characterized as "risk-loving" and therefore courageous, independent, and tough (Andersen 1973; Tunstall 1969; Bourassa and Ashforth 1998; Acheson 1981; Eggert

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and Tveteras 2004; Poggie, Pollnac, and Jones 1995; Pollnac, Poggie, and Cabral 1998), but also resistant to adopting recommended safety measures (Poggie, Pollnac, and Van Dusen 1996; Binkley 1991; Morel, Amalberti, and Chauvin 2008; Davis 2012). However, these studies generally do not consider the institutional frameworks that influence fishers' behavior.

Fisheries management creates the incentives and constraints under which fishers make decisions. Fisheries managers have a wide variety of tools at their disposal, mostly intended to restrict harvest to sustainable levels. It is increasingly realized, however, that aspects of fisheries management can create or worsen market failures, in some cases escalating physical risks for fishers. For example, in response to declines in key stocks in the 1990s, many US fishery management councils limited fleet-wide catches of vulnerable species by instituting catch quotas and input restrictions, such as seasonal closures, gear regulations, and vessel size limits. This type of management, known broadly as "regulated restricted access," has been shown to cause fishing effort to increase along unrestricted margins, dissipating economic rents and creating a "race to fish" (Homans and Wilen 1997; Deacon, Finnoff, and Tschirhart 2011). In a race to fish, harvesters lack property rights to their target catch, and thus have incentive to increase effort in any available avenue to compete with other users. Historically, this has had implications for physical safety when fishers respond by fishing faster, taking trips regardless of weather conditions, overloading vessels with gear or crew, working without sufficient rest, or delaying vessel maintenance.

A great deal of evidence shows that individual fishing quota (IFQ) management systems, which create secure rights to fish, correct and prevent many of the rent dissipation problems associated with regulated restricted access (e.g., Reimer, Abbott, and Wilen 2014; Grafton 1996; Homans and Wilen 2005; Dewees 1998; Casey et al. 1995). A smaller body of research finds complementary improvements in some measures of safety (Pfeiffer and Gratz 2016; Knapp 2016; Casey et al. 1995; Marvasti and Dakhlia 2017). In this paper, we examine the mechanisms through which risk-taking may change in response to changes in fisheries management. In particular, we examine how the shift from regulated restricted access to IFQ management changes incentives that affect exposure to fatality and injury risk among fishers. We investigate the trade-off between safety and economic performance by estimating the marginal rate of substitution between a change in safety-enhancing behavior and expected fishing revenue.

Fishers make many choices that affect their physical risk exposure, but weather is one of the most persistent risk factors they face (Jin and Thunberg 2005; Finnis et al. 2019). Severe weather conditions contributed to 61% of fatal vessel accidents in the United States from 2000 to 2009 (Lincoln and Lucas 2010b) and 80% of fatal accidents on the US West Coast (Lincoln and Lucas 2010a). We posit that the propensity to fish in poor weather conditions is a valid measure of exposure to one of the most important and recurrent types of physical risk. A fisher contemplating whether to delay a trip to wait for a safer day with better weather must weigh the marginal value of a day of fishing. The goal of this paper is to quantify the degree of substitution toward days with better weather conditions when fisheries have transitioned to IFQ management.

We replicate and extend the empirical results developed in Pfeiffer and Gratz (2016) for eight US fisheries that transitioned from various forms of regulated restricted or regulated open access to various forms of IFQ management (also called catch shares,[1] which assign individual or group-level

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[1] NOAA Fisheries has recently adopted the slightly more general term "catch shares" to describe both individually controlled as well as cooperative- and community-controlled quota. See https://www.fisheries.noaa.gov/insight/catch-shares. In this paper, we use the term "IFQs" to refer to programs with the basic characteristics of catch shares management.

privileges to fishing quota). Pfeiffer and Gratz (2016) found that an IFQ program caused a large decline in the propensity to fish in poor weather conditions in one fishery. In this paper, we present a simple conceptual framework that guides our empirical work. The trade-off between physical risk and income can be represented by a production possibilities frontier (PPF), where the denominator of the slope of the PPF is the opportunity cost of actions that decrease physical risk. All else equal, a decrease in this opportunity cost increases the slope of the PPF, and would lead to different utility-maximizing choices about risk. We use daily, fishing vessel-level data to estimate the slope of the PPF before and after the institution of IFQ management in each fishery. Then, we identify fisheries sufficiently similar to each of our eight fisheries that have not undergone major changes in management regimes, and we use them as comparison fisheries in a difference-in-differences specification to identify changes in the propensity of vessels to fish in poor weather. In the Results section, we organize our findings by fishery. We find that risk-taking behavior generally decreases under IFQ management, but the magnitude of the shift differs by fishery. In the Discussion section, we explore the differences across fisheries. In practice, the circumstances and management details surrounding each fishery vary quite dramatically, both before and after the IFQ programs are in place. These institutional differences affect vessels' incentives and constraints, and therefore affect the response to policy changes. For example, we find that that degree of season lengthening after IFQs corresponded to the degree of behavioral change, but the degree of season lengthening is affected by whether a derby-type fishery existed prior to the IFQ program, as well as factors such as a fleet's participation in other fisheries. Careful consideration of such institutional differences can result in the response to policy being predictable, which is important for fisheries managers contemplating policy options.

BACKGROUND

Occupational fatality rates were not reliably tracked in the United States until the early 1990s.[2] When the effort to assess occupational fatality rates began, the data revealed that fishing was not only dangerous, but among the riskiest occupations. The Magnuson-Stevens Act (MSA), which designates national fisheries management standards to ensure sustainable and responsible fishery management (81 FR 71893, October 18, 2016)[3], added a provision on occupational health and safety in 1996. It states, "Conservation and management measures shall, to the extent practicable, promote safety of human life at sea." However, the MSA provides little guidance on identifying, evaluating, or addressing safety issues. The US Coast Guard (USCG) is most directly responsible for the rules and regulations related to safety at sea in US waters. USCG policy has focused on technical solutions to reduce the probability and severity of accidents. The passage of the Commercial Fishing Industry Vessel Safety Act (1988), for example, made safety training and the carrying of emergency safety equipment mandatory. The law has been credited with a decline in the fishing-related fatality rate in the United States (Woodley, Lincoln, and Medlicott 2009; Hiscock 2000). Other regulatory standards established by the USCG include construction standards (2010) and dockside safety examination requirements (2015) for specific classes of new commercial fishing vessels (Kemerer, n.d.).[4]

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[2] https://stats.bls.gov/iif/oshcfoi1.htm

[3] https://www.fisheries.noaa.gov/national/laws-and-policies/national-standard-guidelines

[4] In addition to federal regulation, a few regional programs such as Alaska's At-the-Dock Stability and Safety Compliance Check (1999) and the West Coast's Operation Safe Crab (2003) were developed to address fishery-specific issues (Medlicott 2002; Hardin and Lawrenson 2011).

Fisheries management, on the other hand, has focused primarily on limiting fishing effort to sustain fish populations (Beverton and Holt 1957). The 1976 expansion of national jurisdictions to 200 nautical miles offshore drove interest in managing fisheries to sustain their economic benefits into the future. Limited-entry programs were widely adopted as an instrument to limit the number of participants and address rent-dissipating open-access incentives (Gordon 1954; Scott 1955). However, harvesters licensed under limited-entry programs quickly increased fishing capital, capacity, and power, known broadly as "capital stuffing" (Wilen 1979, 2000). Managers struggled to counteract fishers' ingenuity by limiting key inputs, including vessel tonnage, length, and horsepower; type, size, and amount of gear; season length or vessel days at sea; electronics use; and the number of crew allowed (Wilen 2006). Harvesters' profit maximization objectives turned to outfishing other participants subject to these types of input constraints. Driven by rule-of-capture, stock, and congestion externalities, this phenomenon became known as the "race to fish." Participants, managers, and researchers recognized that the race to fish was leading fishers to take on additional physical risks such as fishing in dangerous weather conditions, overloading vessels with gear or catch, working around-the-clock, delaying maintenance needs until after seasons closed, setting gear in congested areas, and keeping secret their fishing locations (Andersen 1973; Binkley 1991; Hastie 2001; Thomas et al. 2001; Woodley, Lincoln, and Medlicott 2009; Knapp 2016). However, fisheries managers disagreed on what to do. Fisheries scientists tended to blame shortsightedness and greed for the race to fish, while economists emphasized insecure property rights (Wilen 2006).

The 1980s brought a transition to rights-based management in Iceland, New Zealand, Canada, Australia, and the Netherlands (Wilen 2006). The United States soon followed and had four IFQ programs in place by the early 1990s, and an additional 12 programs in subsequent years.[5] While improvements in safety were sometimes mentioned as a likely co-benefit of IFQs, their primary goals were to protect fish stocks, reduce overcapacity, and improve the economic outcomes for fishers and regions dependent upon fisheries. For the most part, fisheries management organizations have not seriously grappled with the contribution of management to occupational health and safety problems (Petursdottir, Hannibalsson, and Turner 2001; Windle et al. 2008).

CONCEPTUAL FRAMEWORK

A simple conceptual framework inspired by Thaler and Rosen (1975) guides our empirical work.[6] Physical risks, such as the probability of an accident, are considered undesirable yet partially avoidable by-products of the fishing production process. Following Thaler and Rosen, complex characterizations of the probability of an accident (such as rates or state-probabilities) can be simplified into a univariate index p denoting the probability of death, or, as $(1-p)$, a measure of "safety." Assuming a production function such as $x = g(p, L)$, where (1) fishers' labor (L) has positive and diminishing marginal product, (2) safety increases the marginal product of labor, and (3) the transformation locus between output and safety is negatively inclined,[7] the trade-off between

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[5] https://www.st.nmfs.noaa.gov/economics/fisheries/commercial/catch-share-program/index#

[6] The conceptual framework is inspired by Thaler and Rosen's (1975) canonical work that derives supply, demand, and market equilibrium prices for job risks, and which provides theoretical underpinnings to much of the literature on the value of a statistical life (Viscusi 1993).

[7] Thaler and Rosen define this as $g_p > 0$ for $0 \leq p < \bar{p}$, where $\bar{p}$ is some "large" technically determined constant, and $g_{pp} < 0$. That is, "accidents are 'productive' up to at least a certain point, and can be avoided only by changing the organization of production within the firm away from marketable output and toward accident prevention" (Thaler and Rosen 1975, 281).

income (generated by output *x*) and physical safety can be characterized by a production possibilities frontier (PPF; figure 1). In this model, safety is produced internally by the firm through its production choices. For example, an operator of a fishing vessel may organize labor inputs such that some aspects of the production process operate more slowly, thereby reducing the probability of an accident. The characteristics of the fishing process determine the degree of concavity of the PPF (e.g., diminishing returns or differing input factor intensities). Its slope at any point describes the opportunity cost of safety in terms of income and is equal to the ratio of marginal costs:

$$-\frac{dSafety}{dIncome} = \frac{\partial Cost/\partial Income}{\partial Cost/\partial Safety}. \tag{1}$$

Weather is an omnipresent risk factor for fishers affecting the probability of accidents. In our empirical application, we focus on weather exposure as a measure of safety. Wind speed, in particular, is highly correlated with other weather-related risks such as wave height. Fishers can avoid high-risk weather by delaying a trip until conditions improve. Thus, in our application, the marginal cost of safety is related to the cost of delaying a fishing trip, including the cost of idle capital and labor.

Economists have documented how this cost can depend on a fishery's institutional setting. For example, additional costs arise because of stock and rule-of-capture externalities resulting from regulated restricted access, or "race to fish," conditions (Homans and Wilen 1997; Abbott and Wilen 2011). Any time a vessel spends not fishing (e.g., waiting for less hazardous weather) decreases the total stock available for capture and increases the marginal cost of capture. These

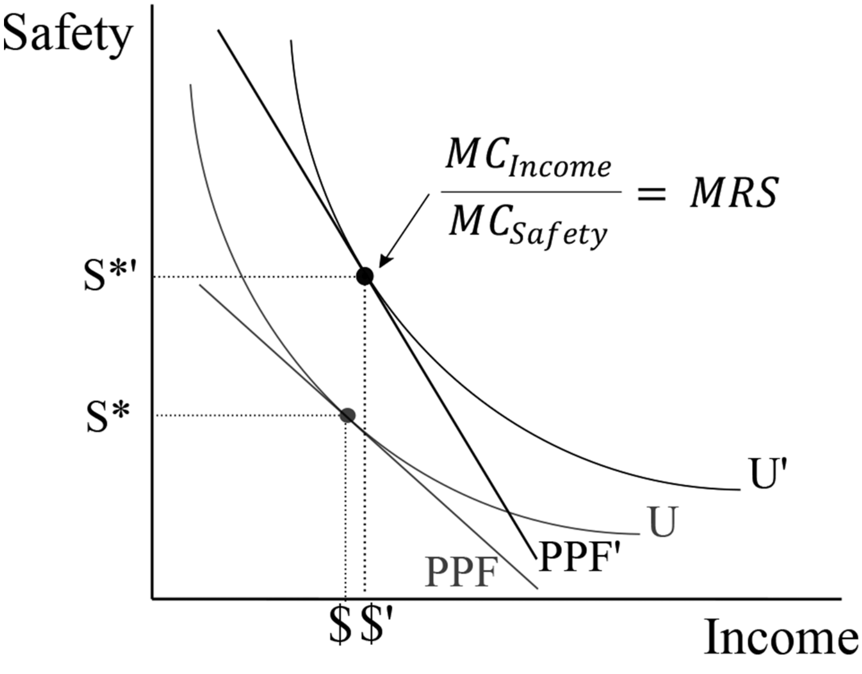

Figure 1. Conceptual Model of the Production Possibilities Frontier under Regulated Restricted Access (PPF) and IFQ Management (PPF′)

externality-induced opportunity costs under a race to fish mean that, holding the marginal cost of expected income constant, the slope of the PPF will be flatter compared with the slope when a fishery is managed to avoid these externalities (including IFQs) (figure 1).

The marginal cost of production (the numerator in equation 1) can be considered the cost to produce additional income from a fishing trip. Marginal profits are generally expected to increase under IFQs because of product quality–induced price increases, the ability to time landings when prices are higher, and cost-side efficiency improvements (Herrmann 2000; Dupont et al. 2005; Wilen and Richardson 2008; M. D. Smith 2012; Reimer, Abbott, and Wilen 2014; Kroetz et al. 2017). However, trip-level marginal profits can also decrease (consider a case of shorter, lower-volume trips over a more extended season, for example). We assume the trip-level marginal production costs are equal under regulated restricted access and IFQs. Thought experiments can be useful to compare potential deviations from this assumption.

Figure 1 shows equilibrium outcomes at the point of tangency between the PPF and indifference curves representing a fisher's preferences about risk and income (U). The convexity of the utility function is derived from risk aversion and imperfect insurance markets (Thaler and Rosen 1975). Thaler and Rosen's framework assumes that firms generate a demand function for job risk, workers generate a supply function for job risk, and a market equilibrium emerges. This characterization may describe some commercial fisheries, where an owner-captain makes the decisions, offers wages, and hires crew that decide to accept the wages and other job conditions. Another common characterization of a fishing vessel is a set of people with interrelated preferences for safety and income that also have control over the fishing production process. Most crews are paid in profit shares rather than wages (Cove 1973), safety outcomes are interdependent (i.e., if the ship sinks all on board are at equal risk), and altruism, egalitarianism, and kinship are common anthropological observations on fishing vessels (Acheson 1981). We ignore the possibility that power dynamics or principal-agent asymmetries are strong enough to require a different equilibrium concept, although this could be an area for future research. At the point of tangency between the PPF and U,

$$-\frac{dSafety}{dIncome} = \frac{\partial C/\partial Income}{\partial C/\partial Safety} = -\frac{dSafety}{dIncome}\Big|_{u=U} = \frac{\partial U/\partial Income}{\partial U/\partial Safety} = MRS.$$

Here, the marginal cost of safety is inversely related to the marginal rate of substitution derived from fishers' preferences at the tangency. That is, as the opportunity cost of delaying a fishing trip decreases, the willingness to trade income for safety increases. The point of tangency determines the chosen levels of safety and fishing income. Assuming preferences are constant, we expect a steeper, outward-shifted PPF under IFQ management to yield higher levels of safety.

The framework leads to the two hypotheses we empirically test using two models: (1) Rights-based fisheries management decreases the opportunity cost of safety-enhancing behaviors relative to regulated restricted access. (2) Fishers under rights-based management will exhibit higher levels of safety-enhancing behaviors relative to regulated restricted access.

In addition, it is important to note that we do not expect the PPFs for different fisheries to be the same. Differences in harvest methods, regulations, input and output markets, and other factors determine the shape and slope of the PPFs. Given a change in management institutions, the magnitude of the difference in slope of the PPF and the difference in safety outcomes is also expected to differ.

EMPIRICAL METHODS

Observed choices can reveal fishers' preferences for taking on physical risk and earning income under the institutions they face. To test the first hypothesis, we develop an empirical model to estimate the marginal rate of substitution (MRS) between the expected revenue from a fishing trip and potential risk under different management scenarios. We measure potential risk as the propensity to take a fishing trip on a high-wind day relative to a non-high-wind day. We analyze fisheries that have undergone transitions from regulated restricted (or open) access to IFQ management, estimating the MRS in the pre- and post-IFQ periods. The MRS can be interpreted as the expected revenue required to start a fishing trip on a high-wind (higher-risk) day. The conceptual model predicts that the MRS will be larger under IFQs, meaning the opportunity cost of delaying a fishing trip is lower. Our estimates are derived from vessel-level models of high-wind avoidance that account for trip-level expected revenue.[8]

We model a vessel's daily fishing decision with a fixed-effects logit model. The fixed effects account for time-invariant unobserved heterogeneity among vessels. The log-odds ratio for starting a fishing trip on day *t* is a linear function of expected revenue and weather in each management regime:

$$\begin{aligned} &\ln[\mathrm{P}(F_{mit} = 1|r_{mit}, w_{mit}, X_{mit}, \alpha_i)] - \ln[1 - \mathrm{P}(F_{mit} = 1|r_{mit}, w_{mit}, X_{mit}, \alpha_i)] \\ &= \gamma r_{mit} + \delta w_{mit} + \beta' X_{mit} + \alpha_i, \end{aligned} \tag{2}$$

where $F_{mit} = 1$ indicates vessel *i* took a trip on day *t* in management regime *m*. $F_{mit} = 0$ indicates that a trip was not taken, and days when a vessel was already at sea or the fishing season was closed were removed from the choice set. Weather, w_{mit}, is a binary variable equal to 1 if there were high winds on day *t* at vessel *i*'s port of departure. Expected revenue, r_{mit}, is estimated using observed prices and catches. Included in $\mathbf{X_t}$ are indicators for day of the week, holidays, and annual fixed effects. The MRS between risk and income, calculated from the estimated parameters, is the compensation (in dollars of expected revenue) that would be required for a vessel to begin a fishing trip on a high-wind day (M. D. Smith and Wilen 2005):

$$MRS = (-\delta/\gamma). \tag{3}$$

Expected revenue is the product of ex-vessel prices and expected catch per trip. Ex-vessel prices are assumed exogenous and are estimated using a 15- to 40-day moving average by state or group of states, if prices vary by state. A longer moving average window was needed for fisheries with less frequent observations to avoid holes in the time series. Most products are commodified and sold frozen, mainly for export, so for fisheries other than scallops and Gulf of Mexico reef fish, prices are plausibly exogenous. We exclude Gulf reef fish from this part of the analysis (discussed below). Scallop prices may experience short-term shocks driven by supply volatility, so a longer moving average was selected to capture general trends in prices.[9] Expected catch per trip was

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[8] We note that it is difficult to separate captains' decisions from those of the crew or vessel owner using this framework. We do not attempt to estimate the curvature of an individual's utility function because we can observe only a vessel's decisions. The results can be interpreted as the value of risk reduction to the aggregation of a vessel's decision-makers, without identifying or attributing the components of the decision to individuals.

[9] A one-day-lagged moving average of scallop prices was also calculated and used, with no major changes in the results.

modeled parametrically: $E(C_{mit}) = \alpha + \gamma'\mathbf{X_{it}} + \varepsilon_{it}$, where $\mathbf{X_{it}}$ contains fishery-relevant characteristics such as vessel size, month, sector, gear, state or area, and biomass (online appendix B).

For several fisheries, expected revenue could not be modeled reliably. The West Coast groundfish trawl and Gulf of Mexico reef fish fisheries are multispecies fisheries with complex, unobservable drivers of the species mix caught. Trip timing and location choices may determine catch composition, which would necessitate additional modeling of target species and location choices and the complex relationships between them. Species composition could also be exogenously determined by the mix of species in the water where the harvester happens to be fishing, which would require spatial and temporal varying biomass estimates for each species. In reality, the mix of species caught is likely to be determined by a highly uncertain combination of human and environmental factors. For the two multispecies fisheries, we estimate equation 2 without including expected revenue and thus cannot estimate the MRS (equation 3). However, our model still estimates the average effect of a high-wind day on the probability of taking a fishing trip under the different management regimes.

We expect the changes in the MRS to have implications for risk-taking, measured as the number of trips taken on high-wind days. To test the second hypothesis, we use a difference-in-differences framework to identify the effect of the transition to ITQs by comparing "treatment" and "comparison" groups before and after the management change. This approach controls for time-invariant differences between fleets as well as time trends that affect both fleets the same way. The comparison fishery is a fishery in the same or nearby region that targets the same or similar group of species as the "treatment" group, but did not undergo a sudden transition in its general management structure. By mirroring the trends in the comparison fishery after the program started, we can project outcomes for the IFQ fishery as if the program were never implemented.

We estimate a negative binomial model of the frequency of trips taken per year (y_i) on high-wind days. The negative binomial is a Poisson distribution generalized by a gamma noise variable that has a mean of 1 and a scale parameter v:

$$\Pr(Y = y_i|\mu_i, \alpha) = \frac{\Gamma(y_i + \alpha^{-1})}{\Gamma(y_i + 1)\Gamma(\alpha^{-1})}\left(\frac{\alpha^{-1}}{\alpha^{-1} + \mu_i}\right)^{\alpha^{-1}}\left(\frac{\mu_i}{\alpha^{-1} + \mu_i}\right)^{y_i}, \tag{4}$$

where $\mu_i = p_i\mu$ and $\alpha = 1/v$, and μ is the mean incidence rate of y per unit of exposure. The exposure variable (p_i) is the number of trips taken by each vessel. The model for the mean of y as a function of exposure, the pre- or post-IFQ period, and the group (treatment and control), and the set of control variables $\mathbf{X}$ is the following:

$$\mu_i = \exp\left(\ln(p_i) + \beta_1 Period + \beta_2 IFQ + \beta_3 Period \times IFQ + \beta'\mathbf{X}\right). \tag{5}$$

The coefficient of interest is β_3, the interaction between time period (pre- and post-management change) and fishery (fishery that transitioned to IFQ and the control fishery). We include other regressors in $\mathbf{X}$ that vary by fishery. Regressors include biomass in fisheries where both the fishery of interest and the control fishery are targeting the same population, and trip length in fisheries where trip length in the fishery of interest and control fishery differs substantially. The percentage change in the number of high-wind trips can be calculated as $(e^{\beta} - 1) \times 100\%$. We also include vessel-level fixed effects that allow the dispersion to vary by vessel, as well as year fixed effects.

DATA

We study eight US commercial fisheries. For each of these fisheries, we identify a suitable comparison fishery where there were no drastic management changes during the time frame assessed. We use data from 12 fisheries in total.[10] The data are from Vessel Trip Reports (VTR), vessel logbooks, vessel delivery reports ("fish tickets"), and fisheries observer reports (table 1). Each trip record includes catch or landings by weight of each species caught, revenue, the port departed from and returned to,[11] trip date, vessel identification number, and vessel characteristics such as length.

To approximate the wind conditions experienced by vessels, we use gridded North American Regional Reanalysis wind speeds from the National Center for Environmental Prediction, which has a 32 km horizontal resolution (Mesinger et al. 2006; Ladd and Bond 2002). Wind speed is constructed as a 24-hour average of the 3-hour averages (the average of eight data points for each 24-hour period) at the port of departure on the day of departure, providing an approximation of the weather conditions at the time and place of the start of the trip. While it can take just one gust to cause an incident, fishers most likely consider forecasted averages when deciding whether to take a trip. The threshold for the binary high-wind variable varies by region (table 1). Vessels and operators are generally equipped for the conditions in which they operate. For example, a wind speed of 7.5 meters/second (mps) would be a very calm day for Alaska crab vessels capable of winter fishing in the Bering Sea, while it would be an uncommonly rough day for vessels in the Gulf of Mexico. The threshold was determined by examining the mean and variance of regional and seasonal wind speeds and vessels' responsiveness to wind speed.

Regional management councils develop IFQ programs in response to local and regional concerns. In practice, fisheries management regulations often evolve toward increasing complexity and vary considerably across regions and fisheries. Understanding these details is essential for specifying our models and interpreting the results. In appendix A, we provide backgrounds and summaries of each program. In table 2, we provide a summary of key management details. Table 3 contains summary statistics for each fishery pre- and post-IFQ, including a Gini coefficient of weekly landings to measure season compression (following Birkenbach, Kaczan, and Smith [2017] using weekly rather than monthly landings).

The Atlantic sea scallop "general category" fishery transitioned from open access to IFQ management in 2010 but had a limited-access transition period for the two years leading up to the IFQ program. During the transition, there were quarterly catch limits which, if reached, closed the fishery. Closures occurred at the end of the 2008 fishing year, and in each quarter of the 2009 fishing year. There was a significant increase in effort in the years leading up to the IFQ program, but most of the vessels that entered during that time did not qualify for the IFQ program and were barred from participating at the beginning of the transition period in 2008. The "days-at-sea" sector is allocated about 95% of the total allowable scallop catch (TAC) and is used as the comparison fishery.

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[10] We attempted to include all federally managed US fisheries that have transitioned to IFQ or catch shares management (https://www.fisheries.noaa.gov/national/sustainable-fisheries/catch-share-programs-council-region). However, a number of IFQ programs were adopted prior to efforts to collect high-quality trip-level data, one program is too recent to have post-IFQ data available, and there were several others for which we could not obtain data.

[11] In several fisheries, only the landing port is identified. For these, we estimate the degree of port fidelity using observer data, and assume that the landing port is the same as the departure port in fisheries with high port fidelity (West Coast Sablefish and the Gulf reef fish fisheries), or we use the previous landing port as the departure port (Alaska crab).

Table 1. Data

Region	Fishery	Program Start	Comparison Fishery	Data	High-Wind Indicator
New England	Atlantic sea scallops, general category	Mar. 1, 2010	Limited-access scallop fleet	2004–2015 Vessel Trip Reports (VTR)	>7.5 mps
Gulf of Mexico	Red snapper	Jan. 1, 2007	South Atlantic snapper fleet; South Atlantic reef fish fishery	2000–2016 logbook data for Gulf reef fishery and South Atlantic snapper-grouper fishery	>6 mps
Gulf of Mexico	Grouper-tilefish	Jan. 1, 2010	South Atlantic fleet targeting grouper-tilefish species complex; South Atlantic reef fish fishery	2000–2016 logbook data for Gulf reef fishery and South Atlantic snapper-grouper fishery	>6 mps
North Pacific	Bristol Bay red king crab	Apr. 1, 2005	Community Development Quota program[a]	2001–2016 Alaska Department of Fish & Game (ADF&G) and the Alaska Commercial Fisheries Entry Commission (CFEC) fish ticket reports	>10 mps
North Pacific	Bering Sea–Aleutian Island (BSAI) snow and tanner crabs	Apr. 1, 2005	Community Development Quota program[a]	2001–2016 Alaska Department of Fish & Game (ADF&G) and the Alaska Commercial Fisheries Entry Commission (CFEC) fish ticket reports	>10 mps
West Coast	Sablefish primary	Jan. 1, 2001	Sablefish trip limit and open access	1994–2012 trip ticket and observer records	>7.5 mps
West Coast	Shoreside Pacific whiting	Jan. 1, 2011	Sablefish primary	2005–2017 trip ticket and observer records	>7.5 mps
West Coast	Groundfish trawl	Jan. 1, 2011	Sablefish primary; sablefish trip limit and open access	2005–2017 trip ticket and observer records	>7.5 mps

Note: [a] After examining the data we determined that the Community Development Quota (CDQ) program could not be used as a control fishery because after the IFQ program implementation in the Alaska crab fisheries, vessels could use both CDQ and IFQ quotas in one trip. While we cannot use a difference-in-differences approach, the CDQ fishery is still of interest as a descriptive comparison.

Table 2. Key Management Details

Fishery	Pre-IFQ Management	Transition Period (if relevant)	IFQ Management
Atlantic sea scallops, general category	Open access, soft catch targets	Limited access, fleet-wide quarterly catch limits	IFQ
Sablefish primary	Limited access, season openings subject to fleet-wide catch limits	Derby main season followed by “mop-up” season with individually allocated quota	IFQ with tradable blocks of quota (“tiers”) and 7-month season
Bristol Bay red king crab	Limited access, season openings subject to fleet-wide annual catch limits	NA	IFQ with 3-month season
Bering Sea–Aleutian Island (BSAI) snow and tanner crabs	Limited access, season openings subject to fleet-wide annual catch limits	NA	IFQ with 7.5-month season
Red snapper	Limited access, season openings subject to fleet-wide annual catch limits and limited open days each month	Vessels fishing for both red snapper and grouper-tilefish had a 3-year period in which only the red snapper IFQ was in effect	IFQ
Grouper-tilefish	Limited access, species-specific season lengths subject to fleet-wide annual catch limits, trip limits	Vessels fishing for both red snapper and grouper-tilefish had a 3-year period in which only the red snapper IFQ was in effect	IFQ
Shoreside Pacific whiting	Limited access, season openings subject to fleet-wide annual catch limits	NA	IFQ with 6.5-month season[a]
Groundfish trawl	Limited access, species-specific bimonthly catch limits, closed areas, gear restrictions	NA	IFQ

Note: [a] The starting date of the shoreside Pacific whiting fishery became May 15 (changed from June 15) in 2015.

Table 3. Means of Key Variables and Fishery Characteristics

	Scallops	Sablefish Primary	King Crab	Snow/Tanner Crab	Red Snapper	Grouper-Tilefish	Pacific Whiting	Groundfish Trawl
Price per pound ($2015)								
Pre-IFQ	$7.68	$2.09	$6.63	$2.17	$3.46	$2.66	$0.082	$0.68
Post-IFQ	$11.41	$2.69	$7.05	$2.03	$4.19	$3.89	$0.115	$0.73
Biomass (thousands mt)								
Pre-IFQ	201.1	252.0[a]	44.7	50.2	24.2	Multispecies	1,752[b]	Multispecies
Post-IFQ	154.5	210.0	34.8	82.0	60.8	Multispecies	2,929	Multispecies
Season length (days)[c]								
Pre-IFQ	365	8	4.5	16.4	99	365[d]	161	365
Post-IFQ	365	214	93	229	365	365	199	365
Number of vessels								
Pre-IFQ	285 (153 qualifiers)	152	243	188	240	550	34	114
Post-IFQ	128	91	70	72	232	324	23	77
Vessel length (ft)								
Pre-IFQ	58	43	115	115	38	36	86	62
Post-IFQ	59	45	118	118	38	37	96	66
Trip length (days)								
Pre-IFQ	1.3	1.9	6.4	10.6	2.1	4.1	1.3	2.2
Post-IFQ	1.3	2.0	7.1	7.7	4.1	4.9	1.5	2.6
Season compression index (Gini coefficient of weekly landings)								
Pre-IFQ	0.338[e]	0.916	0.915	0.928	0.722	0.242	0.805	0.252
Post-IFQ	0.754	0.382	0.341	0.642	0.262	0.207	0.538	0.236

Note: [a] Sablefish biomass is age 4 plus. [b] Pacific whiting biomass is age 2 plus. [c] Pre-IFQ season length is measured as the number of days the season was open. Fishing may not have occurred on all days, and in the case of Pacific whiting, season length can be affected by late-season reallocation. [d] Fishing for at least one major species or complex within the grouper-tilefish fishery was always open, but seasons for some species were restricted (GMFMC 2018). [e] The season compression index for the scallop fishery in the transition period was 0.478.

The West Coast sablefish fixed-gear fishery was the first in our study to adopt an IFQ program, starting in 2001. This fishery had a six-year transition period in which a short derby at the beginning of the season was followed by a "mop-up" season with individually allocated catch limits. Therefore, there was a period in which the same vessels were operating under regulated restricted access and under IFQ incentives at different times in the same year. Since full IFQ implementation in 2001, the sablefish season is open for 7 months.

Both the Bristol Bay red king crab fishery and the Bering Sea–Aleutian Island (BSAI) snow and tanner crab fisheries transitioned from extremely short, several-days-long seasons to IFQ management in the mid-2000s. Under IFQs the seasons are longer but are still limited to several months to protect the stocks during spawning and molting periods. King crab is extremely high value (table 3), so even while the two fisheries are open simultaneously, in practice the king crab fishery ends before the start of the snow and tanner crab fishing. We could not identify a suitable control fishery for the Alaskan crab fisheries. However, we use the preferences revealed during fishing for Community Development Quota (CDQ), which operated under IFQ-like incentives since the 1990s, for descriptive comparisons.

The Gulf of Mexico reef fish fishery is a multispecies fishery that experienced a staggered transition to IFQs. Although many vessels target both red snapper and species in the grouper-tilefish complex, and often on the same trip, the red snapper fishery transitioned to IFQ management three years earlier (2007) than the grouper-tilefish fishery (2010). The pre-IFQ red snapper seasons were limited to a few open days each month. The pre-IFQ seasons for grouper-tilefish species were also often limited, but were staggered across the 17 species in the complex so there was always at least one species available for targeting (appendix A).

Finally, the West Coast shoreside Pacific whiting and groundfish trawl fisheries are technically part of the same IFQ program, but most vessels participate in only one or the other. Before the IFQ program, the shoreside Pacific whiting fishery was a limited-entry fishery with fleet-wide catch limits. The groundfish trawl fishery had a complex bimonthly trip limit system, which effectively spread effort throughout the year because each groundfish species could be caught only up to the limit in each bimonthly period, and managers could shift bimonthly limits up or down within the season depending on the fleet's catch. These temporal limits were eliminated with the groundfish trawl IFQ program and the fishery is now open year-round. The Pacific whiting season is 6.5 months long.

EMPIRICAL RESULTS

We organize the results by fishery. Each table shows the coefficients of interest from the fixed-effects logit model of the probability of taking a fishing trip (equation 2), the MRS calculated from the estimated coefficients (for fisheries where we can reasonably estimate expected revenue) (equation 3), and the coefficients of interest from the difference-in-differences model of the number of trips taken on high-wind days (equation 5).

For each fishery, we estimate the model for the full dataset (every vessel that participated) and for just vessels that participated both pre- and post-IFQ. Different results could indicate a consolidation or participation effect distinct from individual behavior changes. In the scallop fishery, many pre-IFQ general category vessels did not qualify for the IFQ program and we see interesting differences when comparing the entire population with just vessels that qualified and remained in the fishery. We also present both vessel populations in the West Coast groundfish trawl fishery. In other fisheries, there were no significant differences between the results so only the "all vessels" results are shown. The full regression results (including both populations for each fishery) are available in online appendix B. Tests of common trends assumption and additional robustness tests are in online appendix B.

SCALLOPS

In the general category scallop fishery, significantly positive effects of expected revenue and significantly negative effects of high winds result in a positive MRS during the pre-IFQ, transition, and post-IFQ periods (table 4). The MRS is highest in the post-IFQ period, as predicted by the conceptual model (if IFQs reduce the opportunity cost of a day of fishing, the MRS should increase). The MRS is lowest in the transition period when fishing years' TAC was split across quarters, with closures when reached. The results are similar when we exclude "non-qualifiers" that entered the fishery during the lead-up to the transition period but did not qualify for the IFQ program.

Table 4. Scallops

Model and Population	Period					
Individual FE Logit		High-Wind Interaction$^{\pm}$	Expected Revenue Interaction$^{\pm}$	MRS^{+}	*N*	Pseudo R^2
All vessels	Pre-IFQ	–1.642***	0.727***	2.257***	777,661	0.101
		(0.044)	(0.057)	(0.180)		
	Transition	–1.491***	0.974***	1.531***		
		(0.086)	(0.097)	(0.178)		
	Post-IFQ	–1.655***	0.274***	6.031***		
		(0.110)	(0.054)	(1.343)		
Qualifiers	Pre-IFQ	–1.744***	0.630***	2.770***	540,336	0.096
		(0.064)	(0.072)	(0.315)		
	Transition	–1.499***	0.909***	1.648***		
		(0.086)	(0.104)	(0.212)		
	Post-IFQ	–1.664***	0.244***	6.809***		
		(0.109)	(0.055)	(1.687)		
Negative Binomial Difference-in-Differences		IFQ Fishery$^{\pm}$ (diff.-in-diff. estimate)	Comparison Fishery$^{\pm}$		*N*	Pseudo R^2
All vessels	Pre-IFQ	–0.034	Base		6,687	0.222
		(0.209)				
	Transition	–0.203*	–0.508***			
		(0.098)	(0.086)			
	Post-IFQ	–0.280*	–0.646***			
		(0.115)	(0.086)			
Qualifiers	Pre-IFQ	–0.200	Base		5,353	0.205
		(0.272)				
	Transition	–0.196	–0.427***			
		(0.103)	(0.087)			
	Post-IFQ	–0.273*	–0.598***			
		(0.116)	(0.088)			

Note: Vessel and annual fixed effects included. Full regression tables are printed in online appendix B. Dollar values in thousands of \$2015. $^{\pm}$ Clustered robust standard errors in parentheses. $^{+}$ Standard errors in parentheses, calculated based on the delta method. * $p < 0.05$, *** $p < 0.001$.

In the negative binomial difference-in-differences model, the coefficient on *IFQ fishery # Post-IFQ* gives the estimate of the effect of the IFQ program on the proportion of trips taken on high-wind days in the fishery that transitioned to IFQs, and the interaction *IFQ fishery # Transition* identifies the effect of the transition period (the shift from open access to regulated restricted access) (table 4). The all-vessel model indicates that there was about a 24% decrease in the rate of high-wind trip-taking after the IFQ program ($(e^{-0.28} - 1) \times 100 = -24\%$). During the transition period, there was a smaller, marginally significant decrease in the rate of high-wind fishing (18%, significant at the 5% level) compared with the pre-IFQ period. If we only include "qualifiers," the significance and magnitude of the transition period interaction decreases. Many vessels did not qualify for shares, and thus stopped participating at the beginning of the transition period, which could explain the difference.

SABLEFISH

In the West Coast sablefish fishery, the MRS is positive and significant for the mop-up seasons and the post-IFQ fishery (table 5). The coefficient on expected revenue in the pre-IFQ period is not significantly different from zero, so the MRS is undefined. Prior to the IFQ program, the season length was extremely restricted (table 3), meaning that delaying a trip would involve forgoing a large portion of their seasonal catch. The opportunity cost of a delayed trip decreased in the mop-up seasons and in the post-IFQ period. The incentives during the mop-up season were similar to IFQ incentives. The large estimated MRS is likely a result of most vessels having only enough quota for one or two mop-up trips.

Table 5. Sablefish

Model	Period					
Individual FE Logit		High-Wind Interaction$^{\pm}$	Expected Revenue Interaction$^{\pm}$	MRS^{+}	*N*	Pseudo R^2
	Pre-IFQ	–0.331** (0.121)	0.011 (0.006)	–	230,685	0.121
	Mop-up seasons	–1.722*** (0.198)	0.016*** (0.005)	108.651** (33.058)		
	Post-IFQ	–1.225*** (0.139)	0.041*** (0.004)	29.895*** (4.136)		
Negative Binomial Difference-in-Differences		IFQ Fishery$^{\pm}$ (diff.-in-diff. estimate)	Comparison Fishery$^{\pm}$		*N*	Pseudo R^2
	Pre-IFQ	0.528*** (0.128)	Base		6,229	0.283
	Mop-up seasons	–1.194*** (0.311)	0.367 (0.240)			
	Post-IFQ	–0.527*** (0.150)	0.012 (0.122)			

Note: Vessel fixed effects included. Full regression tables are printed in online appendix B. Dollar values in thousands of $2015. $^{\pm}$ Clustered robust standard errors in parentheses. $^{+}$ Standard errors in parentheses, calculated based on the delta method. ** $p < 0.01$, *** $p < 0.001$.

The interaction between *IFQ fishery* and each period identifies the difference-in-differences effect of the management regime on the rate of fishing on high-wind days. We see a decrease in the rate of high-wind fishing in both the mop-up seasons and the IFQ program, by about 70% and 40%, respectively. The sign and magnitude of the estimates correspond to the predictions from the conceptual model and the MRS estimates for each period.

ALASKA RED KING CRAB AND SNOW/TANNER CRAB

For the two Alaska crab fisheries, the pre-IFQ MRS cannot be estimated because the seasons were so condensed that we cannot model expected revenue. Nearly all vessels started fishing on the first day of the season, and for many, that was their only trip of the season (Petesch and Pfeiffer 2019). The revenue that a vessel would forgo to delay a trip for one day was essentially infinite because they would have given up their entire season; thus, the pre-IFQ MRS is undefined. In the post-IFQ period, however, the MRS is positive and significant (table 6).

The Alaska crab fisheries have no suitable control fishery, so we cannot identify IFQ-driven causality for the proportion of trips taken on high-wind days. However, the Community Development Quota (CDQ) fishery, which targets the same species and operated under IFQ-like

Table 6. Alaska Crab Fisheries

Model and Species	Period					
Individual FE Logit		High-Wind Interaction$^{\pm}$	Expected Revenue Interaction$^{\pm}$	MRS^{+}	N	Pseudo R^2
Red king crab	Post-IFQ	–0.261***	0.004***	70.006***	245,358	0.060
		(0.055)	(0.000)	(14.545)		
Snow/tanner crab	Post-IFQ	–0.171***	0.003***	53.352***		
		(0.037)	(0.000)	(12.221)		
Negative Binomial/Poisson Difference-in-Differences[a]		IFQ Fishery$^{\pm}$ (diff.-in-diff. estimate)	Comparison Fishery$^{\pm}$ (CDQ pre-IFQ)		N	
Red king crab	Pre-IFQ	Base	0.220		1,856	
			(0.131)			
	Post-IFQ	0.138				
		(0.099)				
Snow/tanner crab	Pre-IFQ	Base	–0.504***		1,839	
			(0.124)			
	Post-IFQ	–0.796***				
		(0.077)				

Note: Vessel fixed effects included. Annual fixed effects are included in the individual FE model. Red king and snow/tanner crab were estimated simultaneously because most vessels participate in both at different times of the year, and efficiency can be gained by letting the fixed effect be constant over the two fisheries. Full regression tables are printed in online appendix B. Dollar values in thousands of \$2015. $^{\pm}$ Clustered robust standard errors in parentheses. $^{+}$ Standard errors in parentheses, calculated based on the delta method. [a] The fixed-effects negative binomial model would not converge, so Poisson is presented. Annual fixed effects resulted in collinearity in the Poisson because some vessels took only one trip per year in the pre-IFQ period. Biomass is included instead of annual fixed effects, *** $p < 0.001$.

conditions during the pre-IFQ period,[12] can serve as a useful comparison. In the king crab fishery, the rate of high-wind trips taken in the post-IFQ period was not significantly different from vessels taking CDQ trips or regular trips during the pre-IFQ fishery. However, for snow and tanner crab, the rate of high-wind trips taken decreased by about 44% compared with the pre-IFQ period. We observe a similar difference when comparing CDQ trips in the pre-IFQ season to regular pre-IFQ snow and tanner crab trips.

GULF OF MEXICO REEF FISH FISHERIES

We do not model expected revenue for the multispecies fisheries. Instead, we present the results of model 1, adding monthly fixed effects, which control for monthly-level differences in price and catch expectations.[13] We cannot estimate the MRS but show the change in the propensity to start a trip on a high-wind day in each management era (table 7).

The Gulf of Mexico red snapper and grouper-tilefish IFQ programs are linked because many vessels participate in both fisheries, and both species are often caught on the same trip. We present results for each type of trip separately, and for all trips combined.[14] Across all specifications, we see increased aversion to high-wind days after both the red snapper IFQ program and the grouper-tilefish IFQ programs began. We anticipated that the coefficient for grouper-tilefish trips in the “Post-RS-IFQ, Pre-GT-IFQ” period would be insignificant because the IFQ program did not yet apply to grouper-tilefish. However, given the degree of overlap in participation, the negative coefficient is unsurprising. Grouper-tilefish-targeting trips show a weaker response to the high-wind indicator than do trips targeting red snapper. The last column shows the results for the two programs combined.

For the negative binomial difference-in-differences estimation of the programs’ effects on the rate of fishing on high-wind days, the South Atlantic reef fish fishery is the comparison fishery as it does not operate under IFQs. The results should be interpreted with caution because there is some evidence that the common trend assumption may not hold (online appendix B, tables B20–B22). However, we test the robustness of the estimates by using different groups of South Atlantic reef fish trips (table B23, online appendix B). For the red snapper IFQ program, which was implemented in 2007, we find a decrease in the rate of high-wind fishing directly after implementation of the IFQ program, and we find that this effect got larger after the grouper-tilefish IFQ program began in 2010. We also find a decrease in the rate of trips taken on high-wind days for grouper and tilefish trips after implementation of the grouper-tilefish IFQ program. For both programs, the effect is slightly lower when we exclude vessels that exited the fishery after the IFQ programs, but in most cases insignificantly so (online appendix B, table B10). We are most interested in the effect of the two programs on pooled red snapper and grouper-tilefish trips in the Gulf of Mexico. The model indicates that the red snapper IFQ program reduced the rate of high-wind trips, and the effect increased when the grouper-tilefish IFQ program went into effect. The full IFQ program decreased the rate of high-wind trips taken by about 35% compared with the pre-IFQ period.

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[12] The CDQ program was also rationalized post-IFQ, but CDQ quota and regular quota could be caught on the same trip so CDQ trips cannot be considered a separate fishery in the post-IFQ period. The post-IFQ crab fishery is a combination of regular and CDQ fishing.

[13] Results using a continuous function of the day of the year, which controls for cyclical variation in expectations, were very similar but are not shown.

[14] By each type of trip separately, we mean (1) any trip in which red snapper was targeted, (2) any trip in which grouper-tilefish species were targeted, and (3) all trips targeting red snapper and/or grouper-tilefish.

Table 7. Gulf Reef Fish

Model and Population	Period	High-Wind Interaction		
Individual FE Logit		Red Snapper	Grouper-Tilefish	Red Snapper or Grouper-Tilefish
All vessels	Pre-IFQ	–0.451***	–0.581***	–0.515***
		(0.019)	(0.015)	(0.011)
	Post-RS-IFQ, Pre-GT-IFQ	–0.375***	–0.121***	–0.252***
		(0.048)	(0.033)	(0.028)
	Post-GT-IFQ	–0.555***	–0.222***	–0.367***
		(0.035)	(0.030)	(0.025)
	N	562,122	1,700,125	2,279,222
	Pseudo R^2	0.130	0.030	0.050
		IFQ Fishery[a] (diff.-in-diff. estimate)		
Negative Binomial Difference-in-Differences		Red Snapper	Grouper-Tilefish	Red Snapper or Grouper-Tilefish
All vessels	Pre-IFQ	0.044	0.079	0.264***
		(0.116)	(0.042)	(0.041)
	Post-RS-IFQ, Pre-GT-IFQ	–0.167***	–0.009	–0.068*
		(0.043)	(0.032)	(0.032)
	Post-GT-IFQ	–0.462***	–0.325***	–0.373***
		(0.038)	(0.032)	(0.031)
	N	25,184	29,234	27,261
	Pseudo R^2	0.220	0.210	0.210

Note: Vessel and annual fixed effects included. Comparison fishery coefficients are not shown in this table for conciseness. Full regression tables are printed in online appendix B. Clustered robust standard errors in parentheses. [a]All South Atlantic reef fish trips are used as the control fishery for each Gulf fishery sector. * $p < 0.05$, *** $p < 0.001$.

PACIFIC WHITING

For West Coast Pacific whiting, we again see an increase in the MRS from the pre-IFQ period to the post-IFQ period (table 8). However, in the negative binomial difference-in-differences model, we find that the IFQ program had no effect on the rate of fishing on high-wind days.

WEST COAST GROUNDFISH TRAWL

For the West Coast groundfish trawl fishery, we find a surprising result. The degree of aversion to high winds *decreased* after the IFQ program (table 9). This decrease is somewhat smaller if only vessels that remained in the fishery after the IFQ program are included ("stayers").

We interpret the difference-in-differences results with some caution because the groundfish trawl fishery does not have a parallel trend with either control fishery (figure B4, online appendix B). However, we provide the results using both control fisheries to demonstrate the robustness of the unexpected result. For the West Coast groundfish trawl fishery, the estimates indicate that the rate of trip-taking on high-wind days *increased* by over 50% after the IFQ program (table 9). The results are similar across two different control fisheries and for both populations of vessels. In online appendix B, we provide additional results using other non–catch share fisheries that the vessels in the groundfish trawl fishery also participate in as the comparison fishery. While not ideal,

Table 8. Pacific Whiting

Model	Period					
Individual FE Logit		High-Wind Interaction$^{\pm}$	Expected Revenue Interaction$^{\pm}$	MRS^{+}	N	Pseudo R^2
	Pre-IFQ	–0.846***	0.216***	3.916***	39,165	0.125
		(0.105)	(0.033)	(0.667)		
	Post-IFQ	–1.043***	0.073**	14.322**		
		(0.118)	(0.025)	(5.231)		
Negative Binomial Difference-in-Differences		IFQ Fishery$^{\pm}$ (diff.-in-diff. estimate)	Comparison Fishery$^{\pm}$		N	Pseudo R^2
	Pre-IFQ	0.976**	Base		1,923	0.320
		(0.302)				
	Post-IFQ	0.060	–0.574*			
		(0.162)	(0.230)			

Note: Vessel and annual fixed effects included. Full regression tables are printed in online appendix B. Dollar values in thousands of \$2015. $^{\pm}$ Clustered robust standard errors in parentheses. $^{+}$ Standard errors in parentheses, calculated based on the delta method. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 9. West Coast Groundfish Trawl

Model and Population	Period				
Individual FE Logit		High-Wind Interaction		N	Pseudo R^2
All vessels	Pre-IFQ	–1.121***		448,051	0.050
		(0.071)			
	Post-IFQ	0.452***			
		(0.090)			
Stayers	Pre-IFQ	–0.960***		371,366	0.040
		(0.069)			
	Post-IFQ	0.260**			
		(0.082)			
Negative Binomial Difference-in-Differences		IFQ Fishery (diff.-in-diff. estimate)	Comparison Fishery Sablefish DTL/OA	IFQ Fishery (diff.-in-diff. estimate)	Comparison Fishery Sablefish Primary
All vessels	Pre-IFQ	0.467**	Base	1.070**	Base
		(0.142)		(0.401)	
	Post-IFQ	0.447***	0.087	0.421*	0.301
		(0.129)	(0.158)	(0.166)	(0.203)
	N		4,790		2,469
	Pseudo R^2		0.356		0.312
Stayers	Pre-IFQ	0.488***	Base	1.124**	Base
		(0.144)		(0.397)	
	Post-IFQ	0.441***	0.065	0.425*	0.286
		(0.129)	(0.163)	(0.166)	(0.209)
	N		4,230		2,253
	Pseudo R^2		0.348		0.309

Note: Vessel and annual fixed effects included. Full regression tables are printed in online appendix B. Standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

because participation in one fishery could influence participation in another, it allows for common vessel fixed effects. The results provide additional support for the finding that the rate of trip-taking on high-wind days increased because of the IFQ program in the groundfish fishery (table B18, online appendix B).

DISCUSSION

Our empirical models tell fairly consistent stories for each fishery, but the stories differ substantially across fisheries. At first glance, this is a surprising finding. However, the conceptual model indicated that management and other factors affecting each fishery would affect the opportunity cost of a safety-related delay and, therefore, the willingness to pay for a marginal increase in safety. With eight fisheries, we cannot formally test hypotheses about the drivers of the differences across fisheries. However, by examining the results in the context of fisheries management, we can begin to make sense of the differences across fisheries qualitatively.

The conceptual model reveals how the risk-revenue trade-off can change when a fishery transitions from regulated restricted access to an IFQ. The sablefish fishery exemplifies this: the MRS is undefined in the pre-IFQ period and positive and significant for the mop-up seasons (which had IFQ-like incentives) and after the full implementation of the IFQ program. We find a corresponding decrease in the rate of trip-taking on high-wind days. We find complementary results for the Alaska snow and tanner crab fishery. While we were unable to estimate the pre-IFQ MRS because delaying a trip may have meant losing an entire season, we found a positive MRS following the implementation of IFQs. Furthermore, the IFQ program is associated with a decrease in the proportion of snow and tanner crab trips on high-wind days compared with the pre-IFQ period. Though we cannot identify the causal impact of the Alaska crab IFQ program, it was associated with a clear and dramatic increase in season length. Several descriptive studies have highlighted improvements in safety in this fishery (Woodley, Lincoln, and Medlicott 2009; Lincoln and Lucas 2010a).

For the Atlantic scallop general category fishery, the MRS is positive and significant in all periods. However, it is lowest during the transition period, when management shifted from open access to restricted regulated access, and highest after IFQs were implemented. In contrast to the open-access pre-IFQ period, the transition created a race to fish by splitting the fishing year into quarters with TACs that would close the fishery when reached. However, considering the small difference in the MRS between the pre-IFQ and transition periods, it appears that the transition only slightly increased incentives to race. Many vessels had already been excluded from the fishery when the transition period started, potentially reducing competition. The specification limited to program qualifiers shows that taking trips in high-wind conditions did not change significantly in the transition period, but decreased post-IFQ. However, when we include all vessels, we see a decrease in the proportion of high-wind trips during the transition period and after the IFQ. Nonqualifiers may have been racing more in the pre-IFQ period than stayers to compensate for lacking catch history. In addition, although it was a regulated restricted access fishery during the transition period, this lasted only two years and was accompanied by a large decrease in the number of vessels since many did not qualify for quota. These factors potentially minimized the behavioral changes that we might expect under the regulated restricted access incentives in the transition period.

While we cannot estimate the MRS, we find that fishers in the Gulf of Mexico reef fishery increased avoidance of high winds and decreased the proportion of high-wind trips taken after both the red snapper and the grouper-tilefish IFQ programs were implemented. This result is consistent across model specifications. The evidence suggests that the MRS likely increased for reef fishing trips after both programs were in effect because the IFQ programs decreased the rate of high-wind trips taken. Interpretation of the effects of each program individually and both programs together is complicated by the degree of overlap in participation in both fisheries. The red snapper fishing season was the most constrained before the transition to an IFQ program. The seasons for some individual species in the grouper-tilefish complex were also compressed, but at least one species' season was always open (appendix A). Many vessels participate in both programs and frequently catch red snapper and grouper-tilefish on the same trip. Thus, our "red snapper" specification includes several years where many vessels were catching a significant amount of non-IFQ species, which could explain the larger effect on high-wind trip-taking we find after both the red snapper and the grouper-tilefish programs are in place, even for just red snapper trips. The specification using all trips (table 7, last column) is the best estimate of the effect of both programs together, though it may confound each program's effects individually. The multispecies nature of Gulf reef fishing likely reduces the magnitude of the IFQ program's impact by (1) increasing targeting options and reducing the need to race, and (2) creating conditions in which vessels operate under IFQ and non-IFQ incentives on the same trips.

For the last three fisheries, the results are not as straightforward. The MRS is positive for Pacific whiting in both the pre- and post-IFQ periods, but it is nearly twice as large post-IFQ. Yet the count model shows no significant change in the rate of high-wind trip-taking. Similarly, while the MRS is positive in the post-IFQ period in the Alaska king crab fishery (and presumed zero in the pre-IFQ period), there was no significant change in the rate of high-wind trip-taking. In the groundfish trawl fishery, we found a *decrease* in avoidance of high-wind days as well as an *increase* in the proportion of high-wind trips. It is reasonable to surmise that the MRS decreased in this case—an unexpected result. In this fishery, there was no concern about or evidence of a derby before the IFQ. Fishing effort was spread throughout the year because of bimonthly trip limits (see details in appendix A), and total days at sea decreased after the IFQ program even though catch limits were the same or higher. The "all vessels" regression suggests that this was not driven by the exit of more risk-averse vessels.

The conceptual model can be used to provide some guidance on why the results differed across fisheries. In the groundfish fishery, the pre-IFQ bimonthly trip limits resulted in more days at sea than would have been optimal. This management-induced inefficiency could be represented by revealed safety and income level inside the production possibilities frontier, and therefore lower utility. Essentially, vessels forced into "too much" effort would choose a point on their utility curve corresponding to too much safety. Even under the shifted IFQ PPF, a point corresponding to the same or higher utility level could have less safety and more net income.

A potentially complementary explanation is that many vessels participate in multiple fisheries that impose at least some constraints on their time. Most groundfish vessels participate in several unrationalized fisheries on the West Coast, including Dungeness crab, pink shrimp, and salmon. Secure rights to groundfish may induce changes in participation in other fisheries with higher opportunity costs of time (Asche et al. 2007; Cunningham, Bennear, and Smith 2016). Since a fisher is expected to allocate effort to equalize the shadow value of time across fisheries, in effect, the optimal number of days allocated to groundfish may decrease to capture the returns from the fisheries for which rights are not secure. It is also possible that the time dynamics within a season shift such that fishers allocate effort to other fisheries prior to fishing their secure IFQ allocation. Even in cases where vessels participate in multiple IFQ fisheries, differences in marginal costs can drive differences in the opportunity cost of time. For example, many Pacific whiting vessels leave the West Coast after a few months to target pollock in Alaska waters. The timing of participation in the pollock fishery is important, as the summer season opens in June and bycatch problems are increasingly probable later in the season (Stram and Ianelli 2015). This effectively constrains the number of Pacific whiting fishing days on the West Coast. Similarly, there is pressure to finish fishing for king crab before beginning the lower-value snow and tanner crab season. Time constraints driven by participation in other fisheries increase the opportunity cost of a fishing delay, and may help explain the lack of response in high-wind trip-taking in the Pacific whiting and king crab fisheries, despite the increased MRS. In comparison, sablefish and snow and tanner crab harvesters fish for their most valuable species first, allowing more flexibility later in the fishing year.

The pre-IFQ management of sablefish, king crab, snow and tanner crab, red snapper, and Pacific whiting fisheries correspond more closely with the classic regulated restricted access-induced derby described by Homans and Wilen (1997). Sablefish and the crab fisheries were much more constrained by season length, while fishing opportunities in another region constrained Pacific whiting fishing. The red snapper season was also extremely short, but estimation of the effect of IFQs is complicated by the number of species they target simultaneously and the staggered timing of the grouper-tilefish program, which most vessels also participated in. Our modeling shows, however, that trips on high-wind days decreased after both programs were in effect. The West Coast groundfish fishery, in contrast, looked nothing like a derby fishery. The timing of participation was governed by monthly landings limits and the timing of other fishing opportunities. The elimination of monthly limits resulted in a more condensed season, which continues to be affected by participation in other fisheries.

CONCLUSION

Participation in commercial fisheries is risky by nature, and the characteristics of commercial fishing may attract less risk-averse individuals (Dohmen and Falk 2011; Hartog et al. 2003). However, regulated restricted access conditions likely exacerbate risk by creating a race to fish—a market failure whereby harvesters have the incentive to outcompete each other for catch. While they do not eliminate risk, IFQs shift the incentives and constraints faced by fishers such that, through their utility-maximizing choices, fishers choose to take on less risk. In this paper, we find evidence that secure rights to catch decrease the opportunity cost of safety-enhancing behaviors. This value is a critical factor in deciding whether to delay a fishing trip to wait out a storm, for example. The outcomes, in terms of the number of trips that are taken on days with inclement weather, will reflect these opportunity costs. It is highly plausible that a reduction in fishing in poor weather will result in fewer casualties, injuries, and vessel losses.

We find that the degree to which risk exposure declines after an IFQ program depends on the degree to which the race-to-fish incentives were present before it, how much they dissipate upon conversion to IFQ management, and other social, environmental, and management circumstances. Fisheries with extremely condensed seasons, such as West Coast sablefish, Gulf red snapper, and Alaska snow and tanner crab, experienced the largest decline in risk exposure. Fisheries with extremely condensed seasons that remained fairly condensed under IFQs, such as Alaska king crab, experienced less benefits in terms of risk reduction. Fisheries with an abundance of alternative target species, especially those that constrain the season, such as Pacific whiting and king crab, also experienced smaller impacts. Finally, in West Coast groundfish, a fishery in which the pre-IFQ season was lengthened via trip limits, the season length condensed after the IFQ program as vessels pursued greater catch efficiency, and risk exposure increased by our measure.

We interpret our results as indication that increased flexibility in decision-making is the primary driver of safer behavior under IFQs. Property rights are one proven mechanism to increase flexibility, but intertemporal decision-making can still be quite constrained in an IFQ fishery. For example, if fishers have other fishing or non-fishing opportunities that limit the amount of time that they can dedicate to an IFQ fishery, their season may effectively be constrained. Benefits would still accrue to the fishery in terms of captured rents, but fewer precautionary adjustments would be realized. Other types of flexibility-enhancing mechanisms may also be effective at minimizing high-risk fishing but may cost vessels revenue and lower the value of the fishery. To optimize fisher utility, managers should strive for policies that maximize a fishery's value while also maximizing flexibility across the portfolio of fisheries that vessels participate in.

Society has made substantial advances in developing and disseminating at-sea safety training and improving the quality and availability of personal flotation devices (PFDs), survival suits, and other personal safety devices. However, our conceptual framework and empirical results suggest that gains from such advances are bound by, and can be predicted by, the institutional setting. Fishers facing potential pecuniary losses from delaying a trip may gain only marginal safety benefits from wearing PFDs and carrying survival suits if they are compelled to fish in dangerous weather. Fishers operating within an institutional framework where the opportunity cost of a fishing day reflects less-time-constrained marginal profits are more likely to take steps to lower risk to their vessel and its passengers (Lavetti 2020). In fact, the nonmonetary costs of using PFDs (such as reduced mobility or potential for overheating) may be reduced in a fishery that operates more slowly. The opportunity cost of carrying bulky safety equipment is reduced when it is less important to maximize per-trip landings. Policies that increase flexibility for fishers can potentially have multiplicative benefits for occupational health and safety. This work may also contribute to understanding occupational health and safety risks in other industries. At their core, the concepts developed in this paper highlight opportunities to reduce risk exposure by correcting aspects of the regulatory structure that create misaligned incentives. The framework could be applied to other sectors, like agriculture, construction, trucking, or forestry, to determine whether a change in regulatory structure might disincentivize risky behavior.

APPENDIX A

MANAGEMENT DETAILS FOR EACH FISHERY

PACIFIC SABLEFISH PERMIT STACKING (2001)

The "primary sector" of the West Coast sablefish fishery (the sector that transitioned to the "permit stacking program") targets sablefish using pots and longlines. It is allocated nearly 50% of the total annual catch limit of West Coast sablefish.

A license limitation program for the sector began in 1994; this program changed the fishery from open access to one in which participating vessels must have a permit. About 240 permits were issued, but the fishery remained overcapitalized. Seasons were shortened to only a few days in an attempt to constrain catches to the annual catch limit (Hastie 2001).

The sector had the characteristic problems of a derby fishery: overcapitalization, an extremely short season (5–10 days in 1995–2000), and a lack of financial viability for many vessels in the fleet. Managers recognized the dangerous conditions under which vessels were fishing, and shifted the derby fishery's timing. However, the seasons continued to condense and safety concerns escalated (PFMC 2001).

IFQs had entered management discussions as a solution to the problems in the fishery. However, the 1996 Magnuson-Stevens Fishery Conservation and Management Act (MSA, PL 94-264) reauthorization included a moratorium on new IFQ programs. This moratorium was interpreted to include any program that would allow sufficient fishing time and opportunity such that each vessel in the fleet could be reasonably expected to catch the amount allocated to them. In 1997, equal individual catch limits were imposed on all fixed-gear permit holders. However, for these equal limits not to be interpreted as an IFQ, the season length was shortened so that the fleet had no chance of catching the total catch limit. A "mop-up" season was held later in the year to catch the remainder of the catch limit, which again was equally allocated across vessels. It was recognized that this system could not address the derby nature of the fishery, but was seen as the only option available to managers constrained by the moratorium and a first step toward IFQs (Hastie 2001).

In 1998, a "three-tier" system was established in which each vessel's equal limit was replaced with one of three quantities, based on the vessel's historical catch. The tiered limits were meant to improve upon the prior year's equal allocation system. Again, however, the season length was determined such that the projected fleet catch was well below the sum of the individual limits, and the regular season was followed by a mop-up season. The regular seasons continued to be extremely short. For the mop-up seasons, the leftover quota was individually allocated to permitted vessels. Although the mop-up season openings were short, the quota quantities were small, meaning that vessels had plenty of time to fish their mop-up quota. This system continued until 2001.

In 2001, the fishery was granted an exemption to the extension of the MSA moratorium on new IFQ programs. The "permit stacking program" was implemented, which extended the three-tier system by allowing vessels to register up to three permits on a single vessel (to allow capacity reduction), and the fishing season was progressively lengthened over the next few years. In 2001, the season was 2.5 months long, extending to 6 months in 2002–03 and 7 months thereafter.

BERING SEA AND ALEUTIAN ISLANDS CRAB RATIONALIZATION (2005)

The Bering Sea and Aleutian Island (BSAI) commercial crab fishery is currently the third most valuable fishery in Alaska (NOAA NMFS 2018). However, it had extremely high fatality rates throughout the 1980s and 1990s. The high value of crab drove entry into the fishery, which was open access at the time, leading to a high-capacity fleet. In 1995, the North Pacific Fishery Management Council (NPFMC) aimed to reduce fishing effort through a temporary moratorium on new vessels. However, measures of abundance for key crab stocks continued to decline steadily. Catch limits were reduced for the two main stocks: Bristol Bay red king crab (hereafter, "king crab") and Bering Sea snow and tanner crab ("snow crab").

In 2000, NPFMC began a License Limitation Program (NPFMC 2017). Licenses were granted based on historic participation and would later be used to inform the initial allocation of shares under rationalization, and vessel length restrictions were introduced. It was intended to reduce effort and overcapacity, but the number of vessels was still disproportionately high relative to the annual catch allowances and seasons closed after a few days or weeks (table A1).

Rationalization entered management discussions for the BSAI crab fishery starting in 1992 as an approach to address issues related to safety, conservation, and economic stability (NPFMC 2017). The Crab Rationalization (CR) program officially began in April 2005. Shares of BSAI snow and tanner crab and Bristol Bay Red king crab (as well as other crab species) were granted to three agents: harvesters, processors, and communities. The program issued shares for harvesters and processors based on historic participation and reliance on the crab resource.

Communities had received quota allocation through Alaska's Community Development Quota (CDQ) program, which was implemented in 1992 to support economic development and protect community interests in groups of eligible villages in Western Alaska. CDQ groups continued receiving shares as a part of the CR program after it started, accounting for roughly 11% of the annual catch limit for BSAI crab. CDQ groups decide individually how to divide their allocation among vessels or individuals.

The king crab season starts October 15. Since the start of the CR program, the snow crab season officially opens October 15 as well. However, active snow crab fishing begins in January, after king crab fishing ends (table A1).

Table A1. Bristol Bay Red King Crab and Bering Sea Snow Crab Seasons and Quotas

	Bristol Bay Red King Crab			Bering Sea Snow and Tanner Crab		
Season	Days Open	Dates Open	Total Allowable Catch (million lb)	Days Open	Dates Open	Total Allowable Catch (million lb)
2001	4	10/15–10/18	6.60	31	1/15–2/14	25.30
2002	4	10/15–10/18	8.60	25	1/15–2/8	28.50
2003	6	10/15–10/20	14.50	11	1/15–1/25	23.70
2004	4	10/15–10/18	14.30	9	1/15–1/23	19.30
2005	–	–	–	6	1/15–1/20	19.40
2005/06	93	10/15–1/15	18.33	229	10/15–5/31	37.18
2006/07	93	10/15–1/15	15.53	229	10/15–5/31	36.57
2007/08	93	10/15–1/15	20.38	230	10/15–5/31	63.03
2008/09	93	10/15–1/15	20.36	229	10/15–5/31	58.55
2009/10	93	10/15–1/15	16.01	229	10/15–5/31	48.02
2010/11	93	10/15–1/15	14.84	229	10/15–5/31	54.28
2011/12	93	10/15–1/15	7.83	245	10/15–6/15	88.89
2012/13	93	10/15–1/15	7.85	229	10/15–5/31	66.35
2013/14	93	10/15–1/15	8.60	229	10/15–5/31	53.98
2014/15	93	10/15–1/15	9.99	229	10/15–5/31	67.95
2015/16	93	10/15–1/15	9.97	230	10/15–5/31	40.61

Note: The 2005 snow crab year was concluded before the program was implemented.

ATLANTIC SEA SCALLOPS IFQ (2010)

The Atlantic sea scallop fishery is one of the country's most valuable fisheries, exceeding $400 million in ex-vessel value each year (NEFMC 2016). The highest levels of fishing occur in late spring and summer, although the fishery operates year-round (NEFMC 2017). The "fishing year" (FY) starts on March 1. Note that the start of the fishing year shifted to April 1 in 2017 (NMFS 2016), although 2015 is the last year included in our dataset.

The Atlantic sea scallop Fishery Management Plan (FMP) was established in 1982 to maximize the social and economic benefits from the Atlantic sea scallop harvest. In 1994, a limited-entry management system established two permit types: (1) limited access days at sea (LA), and (2) limited access general category (GC). LA vessels receive an allotted number of days at sea each fishing year. LA vessels do not have individual catch limits, and the New England Fishery Management Council (NEFMC) did not start setting annual fleet-wide catch limits until 2008. The LA fleet is generally composed of large vessels taking multiday trips. Those who did not qualify for a LA permit could obtain a GC permit, which was intended for smaller day boats and had a limit of 400 lb per trip. The GC had soft quota targets but was essentially open access. Only the GC part of the scallop fleet later transitioned to IFQs—the LA fleet has remained under days-at-sea management.

The development of the IFQ program began in the early 2000s. The program gained support because of concerns about overfishing and a growing GC fleet. Effort in the GC component of the scallop fishery grew dramatically in the 2000s as vessels tried to qualify for shares of quota in anticipation of losing the opportunity to fish for scallops if a future IFQ program were implemented. There were nearly 600 GC vessels in 2006, up from 240 in 2002 (NEFMC 2017). In 2004 the FMP was amended to create an IFQ program, the primary objective of which was to reduce capacity and overfishing in the GC component of the fishery while maintaining the diverse nature of the fleet, i.e., the ability of smaller day boats to participate (NEFMC 2007). NEFMC adopted a control date that prevented most of the vessels that entered from 2004 through 2007 from qualifying for shares.

Amendment 11 established an Annual Catch Limit (ACL) for scallops. The overall limit would be divided among the LA and GC fleets, with the majority granted to the LA component. It also established FY2008 and FY2009 as transitional years, where the GC fleet was allocated 10% of the projected catch and managed under a quarterly hard catch limit. A separate ACL was announced for each 3-month period, and the fishery was set to close when the quarter's ACL was fully utilized.

Full implementation of the IFQ program began in 2010. Since 2010, the GC/IFQ fleet has received 5% of the ACL, while the LA fleet is allocated 94.5 percent. The remaining 0.5% is granted to LA permit holders who also hold a GC permit. Shares of quota are tradable, though 5% ownership caps were established to prevent overconsolidation (NEFMC 2007, 2017).

The GC fleet was essentially open access prior to the transition period (FY2008–09), so the incentive structure was not the same as that of the "restricted open-access" fishery described by Homans and Wilen (1997). Rent dissipation in the GC fleet would be expected in the long run through free entry, rather than through the race to fish. The LA fleet, under days-at-sea management, also did not (and still does not) face strong incentives to race, although there are some concerns about localized depletion (and managers close areas with higher numbers of young scallops vulnerable to localized depletion). The transition period (FY2008–09) before the official start of the IFQ program in FY2010 may have created the strongest incentives to race to fish relative to the pre-transition and post-IFQ periods. In the transition period, managers limited access to the fishery for the first time, restricting the GC fleet to those who qualified for shares. NEFMC also designated binding catch limits for each quarter in the two transition years that would trigger closures for the GC fishery when reached.

GULF OF MEXICO RED SNAPPER (2007) AND GROUPER-TILEFISH (2010) IFQ

Both the Gulf of Mexico red snapper and the grouper-tilefish complex are managed under the region's Reef Fish FMP, implemented in 1984. The Gulf reef fish plan manages snappers, groupers, tilefishes, jacks, triggerfish, and hogfish. The first assessment of Gulf red snapper in 1988 concluded that the stock was overfished (Goodyear 1988). In response, the Gulf of Mexico Fishery Management Council (GMFMC) applied several measures to the commercial red snapper harvest sector, including quotas, limited-access permits, trip limits, and seasonal closures. The combination of effort controls and catch limits on the high-value species contributed to overcapitalization in the fishery, a problem that persisted through the early 2000s. Despite amendments to the FMP that continued to restrict effort in the directed fishery and to reduce bycatch in the shrimp trawl fishery, red snapper remained overfished until 2009 (GMFMC 2013).

GMFMC's actions throughout the 1990s attempted to balance the stock's future with the interests of fishers historically dependent on red snapper. The first annual quota catch limit was applied in 1990 at 2.79 million lb and reduced to 1.84 million lb in 1991. The quota was increased in 1993 and again in 1996 to 4.19 million lb, a level that stayed in place until the start of the IFQ program in 2007. The 1991 season was the first year the fishery was not open year-round. Seasons became increasingly compressed as fishers harvested the quota in less time. After the 1995 season had to be closed after 52 days, GMFMC split the 1996 quota into two seasons. In the years following, red snapper had "mini-seasons," where fishing was open for a set number of days (about 10–15 days) at the beginning of each month. Between 2000 and the start of the RS-IFQ program in 2007, the number of days the commercial red snapper season was open ranged from 61 to 131 days. Problems included unsafe fishing conditions, low ex-vessel prices, poor regulatory compliance rates, quota overages, and high bycatch and discard mortality rates (GMFMC 2013). The IFQ program was intended to prevent seasonal closures and address the economic and biological ramifications of the derby.

The red snapper IFQ program was introduced in 1995, though it was not implemented until 2007 because of the congressional moratorium on IFQ programs (GMFMC 2016). Since red snapper was still overfished at the onset of the IFQ program, GMFMC revised the rebuilding plan by reducing the quota from 4.19 to 2.99 million lb, decreasing the size limit for retention, reducing recreational bag limits, and specifying reduction targets for fisheries that catch red snapper as bycatch (GMFMC 2013). The stock was declared rebuilt in 2009, after which the annual quota was increased.

Gulf of Mexico grouper-tilefish (GT) are also managed under the Reef Fish FMP. The species are managed as a complex because many occupy overlapping habitat and are targeted with the same gear. The complex was initially composed of 18 species of groupers and tilefishes, but it was reduced to 13 species in 2012. Gulf GT species are currently managed in five categories (table A2). Management of GT species is complex because of their life histories—they are slow growing and long-lived.

Table A2. Gulf of Mexico Grouper-Tilefish IFQ Shares Categories

Category	Species
Gag grouper	Gag grouper
Red grouper	Red grouper
Other shallow-water groupers	Black grouper
	Scamp
	Yellowfin grouper
	Yellowmouth grouper
Deep-water groupers	Snowy grouper
	Speckled hind
	Warsaw grouper
	Yellowedge grouper
Tilefishes	Golden tilefish
	Blueline tilefish
	Goldface tilefish

Note: In 2012, the following species were removed from the GT-IFQ program: red hind and rock hind (other shallow-water groupers), misty grouper (deep-water groupers), and anchor and blackline tilefish (tilefishes). A multiuse flexibility measure applies to the following species: gag, red grouper, scamp, speckled hind, and Warsaw grouper. This allows at least a portion of landings to be debited to another category's allocation.

Prior to the implementation of the GT-IFQ program in 2010, GMFMC controlled fishing effort for GT species using measures such as limited-access permits, trip limits, size limits, seasonal closures, and quotas.

Many seasons closed early in the years leading up to the IFQ program. In 2004, quotas for deep- and shallow-water groupers were reduced while quotas were introduced for the first time for tilefishes and red grouper to prevent overfishing. In response to early closures for deep-water and shallow-water groupers, GMFMC implemented trip limits in 2005, and reduced them in 2006. Trip limits were more effective at keeping the 2007–09 seasons open for shallow-water groupers than for deep-water groupers. In 2009, a rebuilding plan was implemented for gag grouper, which was overfished at the time (GMFMC 2018). Average season lengths in the three years prior to the start of the IFQ program were 365 days for red and shallow-water groupers, 320 days for gag, 170 days for deep-water groupers, and 124 days for tilefishes (GMFMC 2018). All GT seasons became year-round after the IFQ program.

Development of the IFQ program was initiated in 2008 through Amendment 29 to the Reef Fish FMP and the program officially began January 1, 2010, three years after the implementation of the red snapper IFQ program. It was intended to address similar social, economic, and biological issues observed in the pre-IFQ red snapper fishery. Program objectives included mitigating derby fishing, increasing flexibility for harvesters, reducing overcapacity, enhancing profitability, improving safety at sea, eliminating early closures, improving market stability, and reducing bycatch (GMFMC 2018).

The Gulf's red snapper and grouper-tilefish fisheries are similar, and vessels often catch both in the same trip. Since there is a high degree of overlap in participating vessels and the management histories share common themes, vessels in both fisheries are sometimes considered one fleet for analytical purposes, even though the timing of their transitions to catch shares were staggered. Red snapper and red grouper are considered substitutes and earn similar ex-vessel prices. From 2010 to 2016, 89% to 94% of vessels fishing in the RS-IFQ program also harvested GT-IFQ allocation (NMFS and SERO 2018b) and 75% to 87% of vessels targeting grouper-tilefish species also fished red snapper (NMFS and SERO 2018a).

PACIFIC COAST TRAWL RATIONALIZATION PROGRAM (WEST COAST GROUNDFISH TRAWL AND PACIFIC WHITING) (2011)

The West Coast groundfish fishery grew rapidly throughout the 1970s, and when its FMP was established in 1982, biomass was declining, and effort controls were needed (Warlick, Steiner, and Guldin 2018). The fishery was initially managed with per-vessel landings limits but evolved into a complex system of species-, gear-, month-, and area-specific trip limits. High levels of discards have been a concern since the establishment of the FMP. Because the limits applied to landings, not to catches, management provided the incentive to discard species with lower landings limits even when economically or ecologically valuable.

A limited-entry program was adopted in 1994 that limited participants to those with historical landings, and the trip-limit system continued to evolve in complexity to protect species suspected of becoming overfished. However, the fishery remained severely overcapitalized. Nine groundfish stocks were declared overfished from 1999 to 2002. The Pacific Fisheries Management Council and NMFS implemented measures to rebuild stocks, including further reductions in trip limits and closing areas to trawling. In 2003, to reduce the amount of capital in the fishery, a buyback program was implemented. However, the effect of the buyback on effort in the fishery was muted by the purchase and use of permits that were latent at the time. The problems of economic instability, overfishing of many species, and high discard rates remained.

Many of these management changes were designed to facilitate the development of a future rationalization program. After nearly 10 years of discussion and development, a catch share program was implemented in 2011. The shore-based sector of the groundfish trawl fishery includes (1) vessels primarily targeting Pacific whiting, a high-volume, low-value species caught with mid-water trawl gear, and (2) vessels targeting other "non-whiting" groundfish species primarily with bottom-trawl gear. While the groups are not mutually exclusive, fishing for the two "types" of species is quite different. Vessels that target Pacific whiting are larger on average than are vessels that participate in the bottom-trawl fishery.

While regulated under the same FMP, the Pacific whiting fishery's history is different from the bottom-trawl sector. The whiting fishery developed in the 1990s, aided by growth in processing capacity on the West Coast (Warlick, Steiner, and Guldin 2018). Many of the fishers and fishing companies also participate in the Alaska pollock fishery in the Eastern Bering Sea. The two species are processed into similar products and supply similar markets. Highly variable recruitment drives annually fluctuating fishable biomass and landings.

In 1997, a season start date and sector-specific harvest allocations for Pacific whiting were established. The quota was divided among three sectors: shore-based vessels (42%), the mothership sector (24%), and the catcher-processor sector (34%). Shore-based vessels deliver their catch to on-shore processors; the mothership sector is made up of large processing vessels and associated catcher vessels that deliver to them; and the catcher-processor sector is made up of large factory vessels that both catch and process fish. The catcher-processor sector voluntarily formed a cooperative in 1997. The sector-specific harvest allocations eliminated a race to fish between sectors, although derby fisheries within the mothership and shore-based sectors remained a concern. In addition, there remained an incentive to race for bycatch species (which could close the fishery) across sectors.

The catch share program for the shore-based vessels (both bottom trawl and mid-water trawl Pacific whiting vessels) is characterized by individual fishing quotas (IFQs) that are tradable but subject to species-specific and aggregate vessel limits. The program included full at-sea monitoring coverage provisions, and catch is deducted from the quota account.

The IFQ program was intended to reduce the incentive to race to fish in the Pacific whiting shore-based sector, as well as the incentive to race for bycatch across whiting sectors. The shoreside whiting fishery opens on June 15 (changed to May 15 starting in 2015).

However, the IFQ program in the bottom-trawl fishery was primarily concerned with reducing high discard rates. There was little indication of derby fishing in the bottom-trawl fishery. Vessels operated under bimonthly trip limits for each species targeted, along with area closures and gear regulations. This had the effect of spreading effort throughout the year. As a result of the program, discards fell dramatically (Somers et al. 2018). Unlike most other catch share programs, the season length has compressed somewhat compared with pre–catch share seasons (Guldin et al. 2018; Errend et al. 2018).

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