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Occupational Safety and the Shift from Common to Individual Fishing Quotas in the Gulf of Mexico

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We investigate and measure how a shift from a regime of common property to one of private ownership of fishing rights affected the safety of commercial fishing activity. To deal with overfishing and stock depletion of red snapper and grouper-tilefish in the Gulf of Mexico (GOM), various regulatory controls, most notably common quotas and seasonal closures, were introduced in the early 1990s. The resulting "fishing derbies" led to an increased number of accidents and fatalities. We show that the subsequently implemented *individual* fishing quota programs led to a sharp reduction in the number of fatalities, in large part because of lower pressure to make risky trip decisions, in particular under adverse weather conditions.

JEL Classification: Q2, K2, D23

1. Introduction

The objective of this article is to investigate the effect of a policy shift from common to individual fishing quota (IFQ) programs on the safety of commercial fishing. Specifically, we are looking at the case of the Gulf of Mexico red snapper and grouper-tilefish IFQ programs introduced in 2007 and 2010. Various regulatory controls, notably common quotas and seasonal closures, were introduced in the early 1990s in response to overfishing and the rapidly declining stock of red snapper. According to Waters (2001), however, the shorter fishing seasons, along with the common property feature of the quota policy, led to dangerous so-called fishing derbies and an increased number of accidents and fatalities. To resolve the common property rights issue and promote efficiency in the industry, *individual* fishing quota programs were introduced in 2007 for red snapper and in 2010 for grouper-tilefish fisheries. With these programs, the commercial fishing season length was restored to year-round activity, up from about 85 days.

It is widely believed (see, for example, NOAA's annual GOM red snapper IFQ reports) that the reform not only promoted efficiency, but also successfully put an end to fishing derbies, thereby reducing the rate of commercial fishing accidents and fatalities. The underlying intuition is that when fishermen operate with personal quota allocations on one hand, and with significantly more time on the other, they do not need to rush out to sea, but can be selective and choose to fish during the most favorable weather conditions. In contrast to the common quota regime, fish not

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caught today can still be caught later during the year, making it less costly to postpone a trip when weather conditions are poor.

Furthermore, the tradability of IFQs may also have contributed to a lower rate of accidents, as operators of smaller vessels have been able to sell or lease their rights to operators of larger and arguably safer vessels. However, while larger vessels can withstand larger waves and stronger winds, they also tend to stay at sea for longer periods of time, not only increasing the likelihood of running into foul weather, but also inducing more fatigue among crewmembers.

It is also conceivable that the reform may not have had any significant impact on safety if, for instance, fishermen are engaging in risk-compensating behavior (Peltzman 1975): indeed, a sense of relative safety might lead to carelessness, such as not wearing a life-jacket or failing to properly maintain the vessel. Then again, more secure property rights may well have a positive income effect on safety.[1]

Our trip decision data show that, in fact, since the introduction of IFQs, there has been a significant decrease in commercial red snapper and grouper commercial fishing trips under poor weather conditions, as well as a significant drop in the rate of fatalities in the industry.

The remainder of the article is organized as follows. We first provide an overview of the status of occupational injuries in the commercial fishery sector and then review the literature on occupational injuries, in general, and on commercial fishing injuries, in particular. Next, we present the data and our model, an application of Heckman's two-step procedure to deal with a likely selection bias: after all, an accident is only possible if a vessel sets out to sea, a decision hinging on unobserved factors that also determine the probability of a fatal accident. Finally, we discuss the results of the parameter estimates before making concluding remarks.

2. Occupational Injuries in Commercial Fisheries

Commercial fishing is one of the most dangerous occupations in the United States, second only to logging, because of harsh weather, long hours, laborious work, and dangerous work conditions. The 2014 death rates in the commercial fishing industry are significantly above the average fatal occupational injury rate: 80.8 deaths per 100,000 full-time equivalent (FTE) workers for fishers and related fishing workers as compared to the national average of 3.3 per 100,000 FTE (BLS 2015). A Centers for Disease Control (CDC) report by Lincoln and Lucas (2011) shows that during the period from 1992 to 2008, 23% of the U.S. commercial fisheries-related deaths occurred in the Gulf of Mexico (GOM), where harvesters of shrimp, oyster, and snapper/grouper had the highest number of fatalities. Elsewhere, a U.S. Coast Guard (USCG) report by Dickey (2011) on lost fishing vessels and crew fatalities indicates that, during the 1992–2010 period, 2072 U.S. fishing vessels were lost, causing 1055 crewmember fatalities—an average of 56 fatalities per year. While commercial fishing vessels were ranked first in terms of number of fatal injuries with 38% of total marine casualties, recreational fishing was a distant seventh with only 3% of the total marine casualties. Interestingly, 62% of fishing vessel losses occurred while the vessel was engaged in non-fishing operations such as transiting, mooring, moving inbound and outbound, and towing. Flooding and fires accounted for 56% of vessel losses. In 91% of the incidents, there were only one or two fatalities, water exposure (drowning) being the leading cause of fatality at 77%. Dickey also

[1] We thank an anonymous referee for this insight.

shows that the fatalities peaked during the months of October through January, reinforcing the hypothesis that weather plays a key role in fatal marine accidents. The fatality rate is the lowest in the warm waters of the GOM and the highest in the cold waters of the West coast, especially in Alaska where, in 2000, 39 fishermen died in commercial fishing accidents, presumably because an injured person can survive much longer in warmer waters. Because the current USCG regulations focus more on preventing fatal casualties than on preventing loss of vessels, Dickey maintains that the correlation between loss of lives and loss of fishing vessels is very low. According to the same author, vessel age also seems to influence the likelihood of being involved in a fatal fishing accident, the greatest loss being suffered among vessels between 11 and 30 years old.

A drop in the rate of accidents after 1991 is presumably due to the enforcement of the 1991 Commercial Fishing Industry Vessel Regulations. However, the increased use of a common quota system to deal with overfishing in the GOM led to fishing derbies, thus increasing the number of accidents until the quota was reached each year (Waters 2001). It is commonly believed that the IFQ programs have reduced fishing derbies, lowered the likelihood of taking a trip under adverse weather conditions, and thereby led to fewer commercial fishing accidents.

The Commercial Fishing Industry Vessel Safety Act of 1988 was the first legislation that dealt specifically with commercial fishing vessel safety. More recent legislation, known as the Coast Guard Authorization Act of 2010, imposes stronger regulations requiring training for commercial fishing vessel operators as well as design, construction, and maintenance standards for new vessels. The USCG uses several strategies to mitigate safety risks of commercial fisheries, including training, vessel structural considerations, operational factors, and equipment issues. The Occupational Safety and Health Administration (OSHA) recognizes that commercial fishing safety or risk varies by vessel type, fishing gear, targeted species, and geographic region (Hughes and Woodley 2010–2011). A study of the commercial fishing industry in Maine, for example, shows that more than 40% of the vessels studied did not comply with vessel safety regulations and that lack of safety training was common. Furthermore, interviews with the vessel captains with respect to their risk preference suggested that they were risk-loving (Backus and Davis 2011).

NOAA's National Observer Programs (NOP), introduced in the mid-1990s, are another factor potentially affecting risk-taking behavior. Before joining a trip, observers inspect the vessel to make sure that it meets USCG regulations; if it does not meet the safety standards, they will not travel with the vessel and will report it for violation. Neither will observers take the trip if the vessel does not have a valid Commercial Fishing Vessel Safety Examination certificate, a voluntary examination that can be taken each year. Observers cannot, however, stop a vessel from taking the fishing trip without them.[2] While the safety measures in the observer programs are designed to protect the observers, their presence is likely to improve fishermen's safety as well. However, since only a small fraction of the commercial vessels targeting reef fish is observed each year, the effect of the program on safety in the fishery is unclear.

The 2010 Fishing Safety Reauthorization Act is another government effort to improve safety in the fisheries sector. Unfortunately, many items in the act, for example, the requirement that at least one person on board of each vessel receive safety training, have not been implemented due to lack of funds.

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[2] Even though the certificate is optional from the USCG standpoint, but mandatory for the NOAA observers to get on board, there is nevertheless a strong incentive for vessels to obtain the certificate, because they could otherwise be subjected to potentially substantial fines.

3. Literature Review

Since the pioneering work of Oi (1974), there has been a significant amount of research conducted in the area of occupational injuries. For example, Adnett and Dawson (1998) use work accident data from the UK to demonstrate that accidents positively correlate with business cycles, but that a wage premium for high-accident occupations is absent, particularly during high unemployment periods. Viscusi (1979) finds that more educated workers are less likely to get injured, arguing that more educated workers have access to safer jobs and avoid industries with high accident rates. Chelius (1974), on the other hand, conjectures that this negative relation is due to lower propensity to accidents. Kahn (1987) models occupational injuries among nonunion workers in manufacturing and examines their accident propensities. She shows that males are more accident prone, which she attributes to their aggressive behavior. She also finds that the number of hours of work (accidents per standardized full-time worker) increases the propensity for accidents. Job market conditions may also affect the injury risk workers are willing to accept.

Several studies have dealt with the effect of workers' compensation and safety regulations. For example, Ruser (1993) uses counts of injuries in manufacturing to show that increases in workers' compensation benefits increase the rate of non-fatal injuries and the number of days away from work, while they reduce the frequency of fatalities. He acknowledges that workers are likely to receive compensating wages for taking high-risk jobs, but, due to lack of data, he could not resolve the simultaneity problem. Elsewhere, Ruser (1995) uses plant-level manufacturing injury rate data to study the effectiveness of OSHA regulations. He finds a significant positive residual in his estimates, even in the presence of OSHA, arguing in favor of OSHA inspection targeting establishments with high injury rates. Lanoie (1992), on the other hand, benefiting from a richer data set, is able to take the endogeneity of wages into account in his analysis to find that safety policies adopted by Quebec's Occupational Safety and Health legislation are effective in reducing workplace accidents. Decker and Flynn (2008) link worker safety incentives to market structure in the U.S. steel industry by demonstrating that increases in competition motivate firms to increase their efforts in improving worker safety. They find that both prevalence of unions and generous workers' compensation reduce work injuries, while high unemployment is associated with high work injuries.

The literature specifically focusing on injuries in the commercial fishery sector is sparse. Bergland and Pedersen (1997), for instance, focus on a theoretical model, distinguishing transferable and nontransferable quota regimes in Norway. The authors examine the interaction between safety and fishery regulations and explore the moral hazard effects of public safety measures. Bergland and Pedersen argue that owners, captains, and crew can influence the probability of accidents through decisions about both investment (shape and size of vessels) and operations (when and where to fish, what kind of and how much fishing tackle, number of crew and hours on duty). In addition, public services supplied to the operating vessel (navigation and communication systems), weather forecasts and publisher charts, and standards (stability of the vessels, mandatory survival suits, rescue services) can have an important impact on the risk faced by fishermen.

Jin and Thunberg (2005) analyze the 1981–2000 northeastern U.S. coast commercial fleet data and find that weather conditions, vessel location, time of year, and vessel characteristics affect the likelihood of accidents. However, the authors do not find evidence suggesting that changes in either fishery management or revenues influence accident rate. Smith and Wilen (2005) address the perceived notion that, because commercial fishermen face both high financial and physical risk, the risk preference among commercial fishermen must be inherently high. The authors use panel data from the California sea urchin dive fishery to test the risk-loving attitude among

fishermen. Weather conditions and prevalence of great white sharks in the area are used as proxies for physical risk. Their findings do not support the idea that commercial fishermen are inherently risk-loving. Some earlier studies have also concluded that fishermen, in spite of their chosen occupation, are risk-averse (e.g., Bockstael and Opaluch 1983; Mistiaen and Strand 2000; Eggert and Martinsson 2004). These results are surprising, because if fishermen are both rational and risk-averse, one would expect significantly higher earnings for fishermen than in other industries. It is thus conceivable that fishermen do not fully take into account the level of risk that they are facing. A recent survey of perception of occupational risk among Maine commercial fishing vessel captains and fishermen, especially among state-registered vessels, shows that they tend to downgrade the level of their occupational risk, and as a result, they are less likely to comply with safety regulations (Davis 2012). Davis also points to the high level of self-employment in the industry and the consequence that fishermen are economically vulnerable as the variation in the price of catches causes significant financial uncertainty. She also argues that risk-averse fishermen earn significantly less than do risk takers.

Estimating the value of statistical life (VSL) is common in occupational injury and fatality research. Schnier, Horrace, and Felthoven (2009), for instance, use data from Alaskan red king crab and snow crab fishermen and model a commercial fishing captain's choice to fish or not, conditional on the observed risk, to estimate the VSL in that fishery. Weather conditions and policy variables are used as instruments in their estimation to arrive at a VSL of 4.6 to 4.9 million dollars. Interestingly, they also find that the value that captains place on crewmembers' lives lies between 520 and 590 thousand dollars. Of note in the results of the study by Schnier et al. (2009) is that they also point to improved safety in the wake of the 2005 introduction of individual tradable fishing quotas for crab.

4. The Data

The Commercial Fishing Incident Database generated by the National Institute for Occupational Safety and Health contains the Centers for Disease Control's (CDC) fatal commercial red snapper and grouper fishing accident data for the GOM. We combine that data set with the daily trip-level data from the National Marine Fisheries Service's (NMFS) Southeast Coastal Fisheries Logbook Program and Permit Information Management System (PIMS) for the same group of species. The NMFS's Logbook program records fishing activities of commercial fishermen through logbooks required to be submitted for each trip. A daily vessel profile is built for active vessels that have landed at least ten pounds of snapper and grouper/tilefish species each year. The resulting data cover the period from 2000 to 2012 for 3257 Federal and State registered vessels, with 9,967,298 observations. When we look only at data with properly reported vessel characteristics, the number of observations drops to 3,538,051. We have no reason to believe that the observations with missing vessel information are anything but a random choice among permit holders responding to vessel characteristic questions on the PIMS survey.

The vessel profile data are enhanced with several variables, invariant across vessel, but that vary through time. These data stem from the following sources: historical weather information is obtained from National Buoy Data Center (NBDC) reports; unemployment and self-employment data is obtained from the Bureau of Labor Statistics (BLS 2015); presence of observers is provided by the NMFS Reef Fish Observer Program; data on stock size is provided by the NMFS

Southeast Fisheries Science Center; and data on regulatory measures, including quotas and seasonal closures, is taken from Hood, Strelcheck, and Steele (2007) and the Regional Fishery Management Council. Since the reef fishery involves multiple species and closures are species-specific, we constructed a weighted percentage of closures per day using the percentage of revenues generated each day by each species subject to closure out of total revenues from the snapper and grouper fishery.

The list of variables considered in the empirical analysis and their descriptive statistics are presented in Table 1. Despite the dangerous nature of fishing, fatal injury events during commercial trips remain rare events, occurring at a rate of 17.65 accidents for every 100,000 FTE. Furthermore, there has been a 22-percentage-point decrease in the rate of fatal injury events, as it dropped from 19.08 prior to the 2007 IFQ program to only 14.83 per 100,000 FTE thereafter. We further observe that since the institution of the red snapper IFQ program, the number of active red snapper-grouper vessels has been declining, while the number of trips has been decreasing at an even faster rate. As a result, the percentage of active vessels taking a trip each day has been dropping. On average, trips last approximately four days, using 2.70 crewmembers, including the captain, as an average number of FTE employees per trip of 23.13.

We further discuss the following three factors that may affect accident risk: compensation for labor, weather, and vessel characteristics, including fishing gear. First, finding an accurate measure of compensation for labor in the fishery sector is a difficult task because of a lack of fishery-specific data, lack of standard working hours, and the large percentage of the self-employed in some fisheries.[3] Furthermore, the use of a lay system based on a pre-defined share of net revenues (revenues net of most variable costs) to compensate crews is rather common in commercial fishery (McConnell and Price 2006).[4] We use the daily real revenues from red snapper, grouper, and tilefish landing per FTE and per vessel as a proxy for crew wages.[5] Of course, if the variable cost changes with the introduction of the IFQ program, there is a potential systematic bias in the use of this proxy (Abbott, Garber-Yonts, and Wilen 2010). However, a five-year review of the GOM red snapper program does not address any potential changes in the crew share in the fishery (Agar et al. 2014). Elsewhere, Abbott et al. (2010) find little evidence of a major change in the crew share after the introduction of an IFQ program in the Bering Sea/Aleutian crab fisheries.

Second, most measures of weather conditions, such as wind speed and wave height, are correlated; we use only wind speed, which is frequently employed in such studies. Our examination of the univariate characteristics of wind speed and other weather condition variables show that they

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[3] The BLS reports average quarterly weekly wages for two NAICS classification codes, 114 and 1141, at the state level. However, only the west coast of Florida is in the GOM. Some fishery economists use wages in the construction industry as a proxy for wages in the fishery industry, because it is perceived as the opportunity cost for fishermen. Of course, while employment in the construction industry may be the most likely alternative job opportunity for fishermen, seasonal variations in wages differ between fishery and construction.

[4] Use of revenue sharing is common in the industry: typically certain variable costs, such as expenses for fuel and baits, are deducted from revenue before determining the crew share. However, the cost data are only available for a limited time period for a sample of fishing vessels.

[5] Computing FTE employment in fisheries is a challenging task because of the nature and duration of commercial fishing trips, which do not follow the 40-hour-per-week standard. We followed the methodology used by Schnier et al. (2009) to construct FTE, first multiplying the number of days at sea for each trip by the number of crew to arrive at crew days per trip. Next, the number of crew days per trip is multiplied by 24 to arrive at the total number of crew hours per trip, based on the assumption that fishermen are exposed to injury risk throughout the entire trip. Then, assuming 40 hours a week for 50 weeks annual work for typical employees, this aggregate measure of crew hours is divided by 2000 to arrive at the annual FTE for the fishery. The annual rate of fatality is calculated by dividing the 365-day moving average of the number of fatalities from the CDC by the FTE in the fishery.

Table 1. Trip Level Descriptive Statistics

Variable	Definition	Description	Mean (Standard Deviation) All	Pre-IFQ	Post-IFQ
FAT	Fatalities	Daily fatality rate per 100,000 full-time equivalent (FTE)	17.65 (16.14)	19.08 (16.09)	14.83 (15.86)
FTE	FTE crews per trip	Number of FTE crews per trip	23.13 (9.66)	25.26 (9.90)	18.93 (7.59)
WS	Wind speed	In m/s averaged over an eight-minute period for buoys	5.95 (1.75)	5.94 (1.73)	5.98 (1.80)
REVFTE	Revenues per FTE	Real red snapper, grouper, and tile fish gross revenue per FTE in thousands of dollars (using unprocessed finfish PPI index, not seasonally adjusted, 1982 base year)	0.16 (0.14)	0.17 (0.15)	0.14 (0.12)
REVFTE_BMA	Moving average of REVFTE	365-day backward moving average of REVFTE	0.22 (0.29)	0.19 (0.23)	0.25 (0.31)
CREW	Number of crew	On a vessel per trip	2.70 (1.23)	2.69 (1.16)	2.73 (1.05)
DAYS	Days at sea	Number of days on the fishing trip	4.02 (0.01)	3.69 (0.01)	4.86 (0.02)
TOPGH	Hook top gear	Hook top gear is used (yes = 1, no = 0)	0.78 (0.26)	0.79 (0.25)	0.78 (0.27)
TOPGL	Long-line top gear	Long-line top gear is used (yes = 1, no = 0)	0.15 (0.20)	0.16 (0.20)	0.15 (0.20)
SC	Seasonal closures	Percentage of GOM closed to red snapper/grouper commercial fishery	0.11 (0.13)	0.17 (0.14)	0.03 (0.05)
RQ	Remaining quota	Percentage of weighted (by percentage of total revenues) average of pelagic fish quota remaining in the year	0.57 (0.24)	0.54 (0.26)	0.60 (0.21)
OBS	Vessels under obs. progr.	Number of commercial pelagic fish vessels in Observer Program per day	0.30 (0.64)	0.24 (0.52)	0.41 (0.82)
UN	Unemployment	Monthly rate of unemployment in the region	5.03 (0.52)	5.35 (0.28)	5.34 (0.29)

Table 1. (*Continued*)

Variable	Definition	Description	Mean (Standard Deviation) All	Pre-IFQ	Post-IFQ
CHNY	Christmas/New Year	Trip on a Christmas or New Year day (yes = 1, no = 0)	0.01 (0.07)	0.01 (0.08)	0.01 (0.07)
STOCKE	Stock Eastern GOM	Red snapper and yellow edge grouper stock size in the eastern GOM in millions of pounds	37.58 (8.20)	37.48 (4.93)	37.70 (10.84)
STOCKW	Stock Western GOM	Red snapper and yellow edge grouper stock size in the eastern GOM in millions of pounds	40.36 (8.16)	34.40 (6.40)	46.84 (5.62)
IFQRS	Red snapper IFQ	Existence of the 2007 red snapper IFQ program (yes = 1, no = 0)	0.34 (0.47)	0.00 (0.00)	1.00 (0.01)
IFQGT	Grouper IFQ	Existence of the 2010 grouper/tile fish IFQ program (yes = 1, no = 0)	0.15 (0.35)	0.00 (0.00)	0.42 (0.49)
AGE	Vessel age	Vessel age	31.72 (10.72)	32.72 (10.24)	30.20 (11.24)
HP	Horsepower	Average horsepower of the vessels in thousands	0.36 (0.22)	0.36 (0.23)	0.37 (0.23)
LEN	Vessel length	Length of the commercial pelagic fish vessels in feet	38.08 (10.03)	38.22 (10.29)	37.85 (9.57)
HOLDC	Holding capacity	Vessel holding capacity in thousands of pounds	6.60 (10.04)	6.94 (10.78)	6.07 (8.73)
VHULLG	Fiberglass hull	Vessel hull made of fiberglass (yes = 1, no = 0)	0.83 (0.38)	0.78 (0.42)	0.92 (0.28)
DFUEL	Diesel fuel	Diesel fuel used (yes = 1, no = 0)	0.78 (0.42)	0.75 (0.43)	0.81 (0.39)
N	Number of observations	For full sample	3,538,051	2,345,790	1,192,261

follow an autoregressive process of order three, with declining coefficients. This implies that weather patterns in our data go through three-day cycles, which is likely to affect captains' trip decisions.

Third, we focus on vessel characteristics that are likely to affect the probability of accidents at sea, such as vessel length, horsepower, holding capacity, and the primary gear type. Clearly, some of these vessel characteristics are correlated. Hooks constitute 78 % of the gear type used, followed by long lines at 15 %. A very small minority of vessels uses traps, which have, in fact, been outlawed since 2007 in most fisheries in the GOM because of an unacceptable level of bycatch.

5. Sample Selection Model

The probability of an accident is contingent upon the decision to take a fishing trip, which is not random. In addition, there are some unobservable factors that affect both the trip-taking decision and the probability of a fatal accident. Captains observe these factors and adjust their behavior accordingly, thereby possibly causing trips to be less risky under the IFQ program. To avoid bias in a potentially non-random selection among vessels taking a trip each day, an "incidental truncation," we follow Heckman's (1979) two-step procedure ("Heckit"): first, we model the selection process, that is, the probability $P(z_{it}=1|X_{it})$ of a captain taking the vessel (i) on a fishing expedition on a given day (t), as:

$$\begin{aligned} P(z_{it}=1|X_{it}) &= \alpha_0+\alpha_1 WS_{t+1}+\alpha_2 IFQRS_t+\alpha_3 IFQGT_t+\alpha_4 SC_t+\alpha_5 REVFTE_{it-365} \\ &+\alpha_6 UN_t+\alpha_7 CHNY_t+\alpha_8 STOCKE_t+\alpha_9 STOCKW_t+\alpha_{10}\log RQ_t+\alpha_{11} HP_{it} \\ &+\alpha_{12}\log LEN_{it}+\alpha_{13} HOLDC_{it}+\alpha_{14} VHULLG_{it}+\alpha_{15} DFUEL_{it}+\alpha_{16} AGE_{it} \\ &+\alpha_{17}(WS_{t+1}-IFQRS_t)+\alpha_{18}(WS_{t+1}-IFQGT_t)+e_{it}, i=1,\ldots,n; t=1,\ldots,m, \end{aligned} \tag{1}$$

where e_{it} is the random error term. The independent variables, which are defined in Table 1, capture regulatory, economic, environmental, and technological factors. We want to know the effect of a vessel's unmeasured characteristics on the trip decision; the residuals of the trip decision equation carry the information on these unknown factors and are used to construct a selection bias control factor, λ, which is then used in the second equation. Lambda is equivalent to the Inverse Mill's Ratio, capturing all unmeasured (unobserved) characteristics related to the trip decision.

The second equation specifies the probability of a fatal accident during a commercial fishing trip, Y_{it}, as:

$$\begin{aligned} Y_{it} &= \beta_0+\beta_1 WS_t+\beta_2 IFQRS_t+\beta_3 IFQGT_t+\beta_4 REVFTE_{it}+\beta_5\log RQ_t+\beta_6 DAYS_{it}+ \\ &\beta_7 OBS_t+\beta_8\log LEN_{it}+\beta_9(CREW|LEN)_{it}+\beta_{10} HP_{it}+\beta_{11} TOPGH_{it}+\beta_{12} HOLDC_{it} \\ &+\beta_{13} VHULLG_{it}+\beta_{14} DFUEL_{it}+\beta_{15} AGE_{it}+\beta_{16}\lambda_{it}+v_{it}, i=1,\ldots,n; t=1,\ldots,m, \end{aligned} \tag{2}$$

where λ_{it} is the selection bias control factor constructed from the residuals from Equation 1, and v_{it} is the random error term.[6]

[6] The dummy variables for the 2010 grouper and tilefish IFQ and the Coast Guard Authorization Act of 2010 overlap and the IFQGT coefficient reflects the impact of both innovations.

Although our data has both time-series and cross-sectional elements, the cross-sectional units vary each year, so that the data set *appears* to be an unbalanced panel. However, since the cross-sectional units (individual vessels) taking a trip change every day and are a small sample relative to the total number of registered vessels, the data set is not in fact an unbalanced panel and can be better described as an unstructured data set. As a result, we do not perform any diagnostic tests on the residuals of the regression to examine the presence of serial correlation. We estimate Equations 1 and 2 in sequence to take into account the non-randomness in the captain's decision to take a commercial fishing trip. Equation 1 is a probit model, thus assuming that the error term is normally distributed, and we use the maximum likelihood method to estimate its parameters. The least squares method is used to estimate Equation 2.

6. Results

Discussion of the Trip Decision Model

The regression results for the trip decision (Eqn. 1) are reported in Table 2. In our parsimonious specification, Model 1, we focus on weather conditions alone. We then incrementally add other explanatory variables to the model. Because of the inclusion of vessel characteristics in Model 4, the sample size is at its lowest. The coefficients of almost all explanatory variables are statistically highly significant and rather robust across the four specifications. Therefore, our discussion focuses mainly on the results from Model 4, the most inclusive specification of Equation 1, which also yields the best fit based on the value of the log likelihood ratio. To compute the effects of X_{it} on the response probabilities, we use the partial effect at average (PEA) as described in Wooldridge (2013).[7] The PEAs are only reported for Model 4.

As expected, we find that poor weather conditions clearly discourage captains from taking a trip: an increase of wind speed by one meter per second reduces the probability of taking a trip by 0.07.

Consistent with the fact that the institution of the red snapper and grouper tilefish IFQ programs led to a faster drop in the number of trips than in the number of registered vessels, we find that the probability of taking a trip after the introduction of the red snapper IFQ program, all else the same, is approximately 0.06 lower than over the period prior to the introduction of the red snapper IFQ program. The grouper-tilefish IFQ effect is stronger because it is likely that it captures the effect of the Coast Guard Authorization Act of 2010. The interaction effects between weather condition and the two IFQ programs have opposite signs, suggesting that after the introduction of the red snapper IFQ program, the probability of taking a commercial fishing trip during poor weather fell, whereas after the introduction of the grouper-tilefish IFQ program, the probability of taking a commercial fishing trip during poor weather rose.[8]

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[7] Following Wooldridge (2013), in the case of discrete variables, the partial effect at average of the *i*th variable is $\Phi(\hat{\beta}_0 + \hat{\beta}_1\bar{x}_1 + \ldots + \hat{\beta}_i 1 + \ldots + \hat{\beta}_k\bar{x}_k) - \Phi(\hat{\beta}_0 + \hat{\beta}_1\bar{x}_1 + \ldots + \hat{\beta}_i 0 + \ldots + \hat{\beta}_k\bar{x}_k)$, where Φ is the cumulative density function. In the case of continuous variables, the marginal effect of the *i*th variable is $\phi(\hat{\beta}_0 + \hat{\beta}_1\bar{x}_1 + \ldots + \hat{\beta}_k\bar{x}_k)\hat{\beta}_i = 1.2547\hat{\beta}_i$, where ϕ is the normal probability density function. Finally, for variables transformed by the natural log function, the partial effect at average of the *i*th variable is given by $\phi(\hat{\beta}_0 + \hat{\beta}_1\bar{x}_1 + \ldots + \hat{\beta}_i \ln\bar{x}_i + \ldots + \hat{\beta}_k\bar{x}_k)\hat{\beta}_i/\bar{x}_i, = 1.2547\hat{\beta}_i/\bar{x}_i$.

[8] To avoid a potential multicollinearity problem with weather condition and the institution of the IFQ programs, we used a centered interaction effect method for these variables.

Table 2. Heckman Model Estimates - Selection Equation

Variable	Definition	Model 1 Coefficients (St. Errors)	Model 2 Coefficients (St. Errors)	Model 3 Coefficients (St. Errors)	Model 4 Coefficients (St. Errors)	Model 4 PEA
WS_{t+1}	Wind Speed Lead	−0.0515	−0.0539	−0.0522	−0.0552	−0.0693
		(0.0005)	(0.0007)	(0.0007)	(0.0008)	
$IFQRS_t$	Red Snapper IFQ	-	0.0914	0.0457	−0.0383	−0.0581
			(0.0028)	(0.0032)	(0.0033)	
$IFQGT_t$	Grouper-Tilefish IFQ	-	−0.2865	−0.2729	−0.1226	−0.1538
			(0.0036)	(0.0076)	(0.0078)	
SC_t	Seasonal Closures	-	−0.5899	−0.4822	−0.5075	−0.6368
			(0.0089)	(0.0095)	(0.0100)	
$REVFTE_{it\text{-}365}$	Moving Average of REVFTE	-	1.2021	1.2065	0.8484	1.0645
			(0.0030)	(0.0030)	(0.0041)	
UN_t	Unemployment Rate	-	0.0500	0.0301	0.0461	0.0578
			(0.0029)	(0.0031)	(0.0032)	
$CHNY_t$	Christmas/New Year	-	−0.3035	−0.3018	−0.3187	−0.3999
			(0.0162)	(0.0162)	(0.0168)	
$STOCKE_t$	Stocks-East	-	-	0.0021	0.0037	0.0046
				(0.0003)	(0.0003)	
$STOCKW_t$	Stocks-West	-	-	0.0021	−0.0040	−0.0050
				(0.0003)	(0.0003)	
$log\ RQ_t$	Log of Remaining Quota	-	-	-	0.0611	0.0767
					(0.0021)	
HP_t	Horsepower	-	-	-	−0.7144	−0.8964
					(0.0057)	
log LEN_{it}	Log of Vessel Length	-	-	-	0.0845	0.1060
					(0.0065)	
$HOLDC_{it}$	Holding Capacity	-	-	-	0.0029	0.0036
					(0.0001)	
$VHULLF_{it}$	Fiberglass Vessel Hull	-	-	-	0.1155	0.1449
					(0.0034)	
$DFUEL_{it}$	Diesel Fuel	-	-	-	0.4107	0.5153
					(0.0043)	
AGE_{it}	Vessel Age	-	-	-	0.0041	0.0051
					(0.0001)	
WS_{t+1} - $IFQRS_t$	WS-IFQRS Interaction	-	−0.0057	−0.0088	−0.0069	−0.0087
			(0.0014)	(0.0014)	(0.0014)	
WS_{t+1} - $IFQGT_t$	WS-IFQGT Interaction	-	0.0075	0.0079	0.0083	0.0104
			(0.0018)	(0.0018)	(0.0018)	
	Intercept	−0.9287	−1.3953	−1.4153	−1.7970	
		(0.0032)	(0.0164)	(0.0187)	(0.0294)	
	Likelihood Ratio	9702	171,622	173,857	175,287	
N	Number of observations	3,494,528	3,441,744	3,441,744	381,910	

Standard errors are in parentheses. All estimated coefficients are statistically significant at the 99% level.

Since commercial fishing trips prior to the IFQ programs were subject to seasonal closures and fewer vessels took a fishing trip when a larger percentage of the fishery was closed, the seasonality coefficient is negative: a one-percent increase in seasonal closure areas reduces the probability of taking a trip by approximately 0.64. In addition, because the elimination of seasonal closures in 2007 coincides with the removal of mini-seasons, when fishermen had few days to fish and thus

faced high pressure to take a trip, the effect of seasonal closures may capture the mini-season effect.

The results for the percentage of the remaining quota suggest that when the full quota remains at the start of the year, the probability of taking a trip is 0.08 higher. As the percentage of the remaining quota drops, the probability of taking a trip gradually decreases. A plausible explanation is that there is a rush to fish when the quota is fully available at the beginning of the year and post-winter stocks are high, but that captains lose interest in taking a red snapper and grouper trip as the amount remaining in the allocation becomes sufficiently small and they run the risk of landing fish without the required share allocation.

Higher levels of fish stocks increase productivity and increase the incentive to go fishing. Surprisingly, while the stock size in the eastern GOM improves the probability of taking a commercial fishing trip, the impact of stock size is negative in the west. Our estimated parameters are statistically significant. We tested for multicollinearity between the stock sizes of the two geographic areas. While the simple correlation coefficient between east and west stocks is not high, the Variance Inflation Factor (VIF) points to the presence of multicollinearity between the two stocks: the VIF for the east and west stocks are 5.3 and 7.7, respectively.

Captains are likely to take recent information on revenues per FTE into account when deciding whether to take a trip. Since trip lengths vary, we use the 365-day backward moving average of revenues in the model and find that a one-thousand-dollar increase in lagged revenues per full-time crew increases the probability of taking a trip by 1.07. The large effect of this variable is due to the scaling of the revenue figures.

Since high unemployment reduces the chances of alternative job opportunities, captains should find it easier to find interested crew and thus take a fishing trip, but the magnitude of the effect turns out to be small. Moreover, like most other people, captains are less likely to take a fishing trip during major holidays such as Christmas or New Year. During these holidays, the probability of a captain choosing to take a trip drops by 0.40.

Larger vessels and vessels with less powerful engines tend to improve the probability of taking a trip. These factors may also be a proxy for the inverse of the age of the vessel, to the extent that vessels have, on average, been getting larger and more powerful over the years.[9]

Discussion of the Fatal Injuries Model

Estimation results for the fatal injuries function, correcting for the selection bias based on Model 4 (Table 2) to capture the effect of unobservable variables, are presented in Table 3. We begin with Model 4-1 as a very parsimonious version of Equation 2 by including only the unobservable variable and the dummy variable for the introduction of the red snapper IFQ program; we then progressively add observable risk factors to the equation. This inclusion of the control variables allows us to more accurately measure the role of the IFQ program in the observed drop in

[9] We also experimented with an alternative set of models, in which we separated the data set into two groups–pre- and post-red snapper IFQ program. We then followed the same process to estimate the parameters for the trip decision and fatal injuries equations. An intriguing result from the trip decision equation is the response to poor weather conditions. Comparing the size of the coefficient across the models suggests that captains give more weight to wind speed in making their trip decision after the IFQ than they did before the IFQ. This implies that their attitude towards risk associated with poor weather conditions has changed. Also, in the sub-sample after the IFQ, the role of poor weather conditions in causing fatal accidents is significantly reduced.

Table 3. Heckman Model Estimates - Main Equation

Variable	Definition	Model 4-1 Coefficients (St. Errors)	Model 4-2 Coefficients (St. Errors)	Model 4-3 Coefficients (St. Errors)	Model 4-4 Coefficients (St. Errors)
WS_t	Wind Speed	-	0.4810	0.4017	0.2660
			(0.0158)	(0.0160)	(0.0170)
$IFQRS_t$	Red Snapper IFQ	−1.2483	−1.2772	−1.5168	−1.6091
		(0.0621)	(0.0620)	(0.0645)	(0.0664)
$IFQGT_t$	Grouper-Tilefish IFQ	−6.9798	−6.9095	−7.0349	−7.1476
		(0.0831)	(0.0830)	(0.0837)	(0.0859)
$REVFTE_{it}$	Revenues Per FTE	-	-	7.1633	8.7989
				(0.1900)	(0.2002)
Log RQ_t	Log of Remaining Quota	-	-	0.4674	0.7787
				(0.0507)	(0.0529)
$DAYS_{it}$	Days at Sea	-	-	0.2572	0.2647
				(0.0074)	(0.0082)
OBS_t	Vessels under Observer Program	-	-	0.7111	0.7107
				(0.0371)	(0.0370)
log LEN_{it}	Log of Vessel Length	-	-	-	1.0842
					(0.1878)
$(CREW/LEN)_{it}$	Crew/Length Ratio	-	-	-	0.2285
					(0.0760)
HP_{it}	Horsepower	-	-	-	−5.3475
					(0.1998)
$TOPGH_{it}$	Hook Top Gear	-	-	-	−0.3462
					(0.0692)
$HOLDC_{it}$	Holding Capacity	-	-	-	0.0504
					(0.0035)
$VHULLG_{it}$	Fiberglass Vessel Hull	-	-	-	1.4006
					(0.0895)
$DUEL_{it}$	Diesel Fuel	-	-	-	2.5015
					(0.1525)
AGE_{it}	Vessel Age	-	-	-	0.0373
					(0.0030)
λ_{it}	Lambda	2.0044	1.8074	4.5637	8.8415
		(0.0871)	(0.0872)	(0.1115)	(0.1878)
	Intercept	15.7818	13.3607	6.8020	−5.7478
		(0.1318)	(0.1538)	(0.2180)	(0.8458)
	AIC	2,828,885	2,827,962	2,825,427	2,824,168
	Adjusted R^2	0.03	0.04	0.04	0.05

Standard errors are in parentheses. All estimated coefficients are statistically significant at the 99% level.

fatal injuries in recent years and yields a better fit in terms of Akaike's Information Criterion (AIC).

Since the IFQ programs have allowed captains to make trip decisions without a seasonality constraint, they are expected to take fewer risks with respect to poor weather conditions, and we thus expect the IFQ coefficients to take a negative sign. Indeed, the results from Model 4-1 show that the red snapper IFQ program reduced the number of fatalities by 1.25 per 100,000 FTE. The effect of introducing the grouper-tilefish IFQ program is more significant (7.0 fatalities per 100,000 FTE), perhaps in part due to its overlap with the introduction of the Coast Guard Authorization Act of 2010. The value of lambda suggests that the unobservable factors contributing to the likelihood of a fishing trip increase the number of fatal injuries by 2.0 per 100,000 FTE in this

model. Inclusion of the wind speed risk factor in Model 4-2 shows that a one-meter-per-second increase in the wind speed raises the rate of fatal accidents by 0.48 per 100,000 FTE.

The inclusion of additional control variables in Model 4-3 slightly reduces the effect of both poor weather conditions and the introduction of the red snapper IFQ program, while the grouper-tilefish IFQ effect is rather robust. In this model, the unobservable factors contributing to the likelihood of a fishing trip increase the number of fatal injuries by 4.56 per 100,000 FTE. A one-day increase in the length of the trip leads to an increase of 0.26 fatal injuries per 100,000 FTE, presumably because of associated fatigue among the crew, the increased likelihood of errors, and the crew's slower response to accidents. The rate of fatal injuries also increases when the percentage of remaining quota is high at the beginning of the season, possibly pointing to crowding and negative production externalities. Fishing revenues appear to encourage risky behavior as fatal injuries increase by 7.16 per 100,000 FTE in response to a one-thousand-dollar increase in revenues per FTE. In other words, using the reciprocal of this coefficient, fishermen's trade-offs between revenues and risk of fatality from commercial fishing of red snapper and grouper/tilefish is $140 for a 0.00,001 increase in the probability of a fatal injury.

Model 4-4 includes all measurable risk factors, including the physical characteristics of the vessels. For example, the results show that when a vessel is equipped with hooks, the number of fatal injuries per 100,000 FTE is reduced by 0.35, which may be due to fishing closer to shore than vessels equipped with long lines. We initially posited a nonlinear relation between vessel length and the probability of a fatal accident, with chances of an accident being lowest for both the smallest vessels, perhaps because these select less risky fishing sites, and for the largest vessels, because their size provides them with more stability in turbulent waters. However, surprisingly, and at odds with the findings of Jin and Thunberg (2005), there is a clear positive relation between vessel length and the chance of fatal injuries: a 100% increase in the length of the vessel increases the rate of fatal injuries by 1.08 per 100,000 FTE. Other control variables include vessel age. While aging vessels are more likely to be involved in accidents, the magnitude of the age coefficient suggests that its effect on the fatality rate is small. In terms of risk reduction from the IFQ programs, the results from Model 4-4 are more consistent with the model 4 results in Table 3.

Higher revenues from a trip encourage risk taking; consequently, the coefficient of fishing revenues per FTE is expected to be positive. In fact, β_4 represents the marginal rate of substitution between the returns from a fishing trip and the risk of fatal injury. Finally, we find that the ratio of crew to vessel length, which captures crowding on the vessel, contributes to fatal accidents.

7. Conclusions

This analysis contributes to the studies of fatal occupational injuries in general and the implications of changes to the property rights system on such events, in particular. We considered two empirical models to establish a link between a captain's decision to take a red snapper/grouper-tilefish commercial fishing trip and the likelihood of a fatal injury incident. We introduced a group of control variables capturing geographic, market, and regulatory-specific factors such as weather, unemployment rate, and quota levels, as well as price lag and vessel-specific factors such as technical vessel characteristics. Most of the results are intuitive: high wind speed reduces the odds of taking a trip; availability of crew labor, or lack of alternative job opportunities for the self-employed captains, signaled by high unemployment rate, increases the odds of taking a trip; larger vessels

take longer, but less frequent trips. We also found some support for the positive effect of the stock size in the eastern GOM on the decision to fish.

Our primary objective, however, was to test the hypothesis that the change from a common property regime, with quota restrictions and seasonality, to private ownership of share allocations, without seasonal closures, reduces the need to make risky trip decisions and improves safety. Our findings support this hypothesis. In other words, the introduction of a private property rights regime for red snapper has reduced the pressure to fish under unfavorable weather conditions. This is reflected in the trip decision process. However, although captains are less likely to take a trip under poor weather conditions, weather conditions remain a factor in fatal injuries.

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