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Evaluating the impact of individual fishing quotas (IFQs) on the technical efficiency and composition of the US Gulf of Mexico red snapper commercial fishing fleet

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ABSTRACT

This study examines the impact of individual fishing quotas (IFQs) on the technical efficiency (TE) and composition of the Gulf of Mexico red snapper commercial fishing fleet. Employing a parametric stochastic distance frontier framework we find that IFQs improved the TE of the vertical line and bottom longline fleets. Our results suggest that the observed TE gains were mainly driven by the retirement of less efficient vessels and, to a lesser extent, by efficiency gains of the remaining vessels. We also document changes in output and input distance elasticities and in returns to scale following the introduction of IFQs. The paper also investigates the impact of regulations and weather on productivity and the effect of crowding on TE. Policy implications stemming from these results are also discussed.

Introduction

Over the last fifty years there has been a growing consensus that the main reason behind the unsustainable use of fisheries resources lies in the inability to overcome collective action dilemmas (Acheson, 2006). These dilemmas refer to situations in which individuals' short-term interests yield outcomes that are detrimental to society's long-term interests. In the case of fisheries, while collectively fishers recognize the need to conserve and manage fish resources, individually, they have the incentive to fish as intensively and swiftly as possible before someone else does because of the difficulty of devising and enforcing rules to limit fishing. To address these collective action dilemmas, fishery management agencies have traditionally resorted to command and control policies to limit fishing effort. These command and control policies favor restricting the use of inputs and/or setting catch limits for the entire fleet. While these policies have had limited success protecting fish stocks, they more often have resulted in overexploitation, effort creep, excessive investments, rent dissipation and social dislocation because they have failed to provide fishers with an enduring incentive to fish sustainably (Aguilar Ibarra et al., 2000; Wilen, 2000; Grafton et al., 2006; Sutinen, 1999; Ostrom et al., 1999).

Three possible governance structures have been advanced to solve these dilemmas including property rights (or exclusive harvesting privileges[1]), government management and local community management (Ostrom et al., 1999). While there is no agreement on the best governance structure, economists have favored the use of property rights because they promote resource stewardship and improve economic performance. Grafton et al. (2000) argue that property rights encourage fishers to employ capital and labor judiciously rather than fostering excessive investments to outcompete other fishers.

One of the most well-known management failures has been the Gulf of Mexico red snapper fishery. Decades of regulation, which included quotas, access controls, trip limits and restricted fishing seasons, not only failed to protect and rebuild the declining stock, but also led to overcapacity and derby fishing conditions that resulted in market gluts, depressed prices, higher harvesting costs, and unsafe fishing practices (Waters, 2001). In response to these past failures the Gulf of Mexico Fishery Management Council (hereafter Council) established an individual fishing quota (IFQ)

[1] In the United States, IFQs are legally defined as 'revocable' privileges rather than property rights because the Magnuson-Stevens Fishery Conservation and Management Act reserves the right to modify, limit or revoke them without the need to compensate the holder.

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program for the commercial red snapper fishery on January 1, 2007.

Under an IFQ program, fishers are afforded a secure (often tradable) harvesting privilege that entitles them to a share (or percentage) of a fishery's total allowable catch (TAC). Because fishers have a secure harvesting privilege they no longer have the incentive to harvest as fast as possible in order to preempt the activities of other fishers. Hence fishers can adjust the scale and scope of their operations to take advantage of market conditions. IFQs can also improve technical efficiency (TE) because fishers can select (manage) freely the optimal combination of inputs to harvest fish. In addition, if shares are tradable, they are expected to gravitate towards the most efficient producers, thereby shedding excess harvesting capacity as marginal producers exit the fishery (Solís et al., in press; Dresdner et al., 2010; Squires et al., 2010; Pascoe and Coglan, 2002; Asche et al., 2009; Brandt, 2007; Weninger, 1998). Moreover, IFQs provide greater certainty about future landings which lowers the financial risk associated with long-term planning and investments. Due to its potential benefits IFQ programs have become a popular management tool worldwide. Arnason (2012) reports that about a quarter of the world's fish landings now comes from IFQ fisheries.

The goal of this study is to analyze the impact of the IFQ program on the TE and composition of the Gulf of Mexico red snapper commercial fleet.[2] Drawing on a stochastic distance frontier (SDF) model, which accounts for the multiproduct nature of commercial fish production, we find that IFQs enhanced the TE of the commercial fleet. Specifically, the analysis shows that these efficiency gains are mainly driven by the retirement of less efficient vessels in the fleet, and to a lesser extent, by efficiency gains of the remaining vessels.[3] Changes in output and input distance elasticities and in returns to scale following the introduction of IFQs were also found. The paper also discusses the impacts of regulations and weather on productivity, and the effect of crowding on efficiency.

The rest of this article is organized as follows. First, we present a brief description of the red snapper management history. Then, we outline the methodology and describe the data and the empirical model. This is followed by a presentation and analysis of the results. The article concludes with a summary of the main findings and policy implications.

Overview of the fishery

Red snapper (*Lutjanus campechanus*) is the most economically important species of the shallow-water snapper complex in the Gulf of Mexico. Vessels using vertical lines are responsible for over 95% of the commercial landings of this species, followed by vessels employing bottom longlines which take most of the remaining landings. In 2011, these fleets landed about 3.24 million pounds (gutted weight) of red snapper worth $13.8 million dollars (Agar et al., in press).

The red snapper fishery has a long and complicated management history. The Council first began managing this species when it adopted the Fishery Management Plan for Reef Fish Resources of the Gulf of Mexico (FMP) in 1984. The FMP sought to attain the greatest overall benefit to the nation by increasing the yield of the reef fish fishery, minimizing user conflicts in near shore waters and protecting juvenile reef fish and their habitats (Waters, 2001). Four years later, the red snapper stock assessment showed that the stock was significantly overfished and that fishing mortality had to be reduced by 60–70%. As a result, the Council established a red snapper TAC to be shared between the commercial and recreational sectors, imposed geographic restrictions to protect large red snappers, and established reef fish permits for vessels to operate in federal waters (Hood et al., 2007). However, a second stock assessment conducted in 1990 concluded that the red snapper stock was in worse shape than anticipated, which resulted in reduced commercial quotas, a moratorium on the issuance of new reef fish permits, and red snapper daily trip limit endorsements (i.e., Class 1: 2000 lbs and Class 2: 200 lbs) based on the vessel landing history. Despite these efforts, fishing capacity continued to increase and quotas were filled progressively sooner. For instance, in 1992, the quota was filled in 53 days (Fletcher, 1999).

In 1995, a new stock assessment showed biological gains which allowed the Council to increase the TAC; nonetheless, derby conditions continued despite splitting the commercial season into a spring season and a fall season. Concerns over the adverse social and economic impacts of progressively shorter fishing seasons, derby fishing and unsafe fishing conditions led to the development of Amendment No. 8, which introduced an IFQ program in 1995. However, the US Congress established a moratorium on IFQs, which led the Council to institute fishing mini-seasons to ameliorate the detrimental impacts of derby fishing. Initially these mini-seasons lasted for the first 15 days of each month (or until the quota was reached) but over time were reduced to the first 10 days of the month.

Finally after two referendums, the Council implemented Amendment No. 26 on January 1, 2007, which introduced the red snapper IFQ program to reduce overcapacity and to eliminate, to the extent possible, the problems associated with derby fishing in the commercial fishery. The IFQ program established an individual transferable quota regime which placed a 6% cap on the accumulation and transfer of IFQ shares. However, there was no cap on the amount of IFQ allocation (i.e., annual leasing of quota) that may be held and transferred during the calendar year. Additional details about the red snapper IFQ program and its evolution can be found in SERO (2012) and Agar et al. (in press).

Methodology and data

Stochastic distance frontier

Commercial fishing is a unique economic activity characterized by its randomness and multi-species nature (Kirkley et al., 2002). Two alternative methodologies have dominated the literature to accommodate multi-outputs when estimating production processes and TE for fisheries: (1) the deterministic non-parametric data envelopment analysis (DEA; e.g., Herrero et al., 2006; Färe et al., 2006; Andersen, 2005); and (2) the parametric SDF (e.g., Pascoe et al., 2012; Orea et al., 2005; Fousekis, 2002). Orea et al. (2005) and Felthoven et al. (2009) argue that due to the random nature of fishing processes, SDF is the preferred methodology since it allows for 'noise' in the estimation of an empirical model. In other words, unlike DEA, SDF does not assume that all deviations from the frontier are solely explained by inefficiency but also allows for stochastic or random events. In addition, the parametric nature of the SDF generates valuable information on the relationship between harvest levels, and factors of production and regulatory and environmental variables.

SDF can be estimated using an output- or input-orientation. The output distance function (ODF) measures the maximum amount by which an output vector can be proportionally expanded and still be producible with a given input vector, whereas the input distance

[2] In this study we focus on the impact of IFQs on fish production, TE and fleet composition; however, IFQs may also yield potential revenue effects as shown in Homans and Wilen (2005). This is an area that merits further research.

[3] Many of the vessels that left the red snapper fishery exited because of the low initial allocation received and the severe red snapper quota cutbacks at the onset of the IFQ program. However, most of the displaced vessels continued fishing in other reef-fish fisheries.

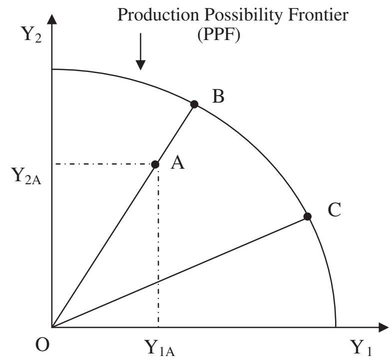

Fig. 1. Illustration of a distance function with an output orientation.

function (IDF) measures the maximum amount by which the input usage can be proportionally reduced to produce a given vector of outputs. Orea et al. (2005) argue that output-oriented models are preferable for efficiency analyses of fishing operations because fishers cannot readily change factors of production during the fishing trip (e.g., vessel size). Fig. 1 illustrates the concept of an ODF, where given two outputs, Y_1 and Y_2, the output possibility set is the area bounded by the production possibility frontier (PPF). The ODF score of a vessel using a fixed amount of inputs to produce output mix A is equal to the ratio OA/OB. When the firm operates efficiently (points B and C on the PPF), then the score of the ODF is equal to 1 (Coelli and Perelman, 1999).[4]

Mathematically, the ODF can be expressed as:

$$D_o(x,y) = \min\{\theta > 0 : (y/\theta) \in P(x)\} \tag{1}$$

where $P(x)$ is the set of feasible output vectors obtainable from the input vector x and $D_o(x,y)$ represents the distance to the production frontier. If $D_o(x,y) \leqslant 1$, then (x,y) belongs to $P(x)$. Additionally, if $D_o(x,y) = 1$, then y is located on the outer boundary of $P(x)$ (Perelman and Santin, 2011).

Cuesta and Orea (2002) show that a well-behaved ODF must be non-decreasing, positively linearly homogeneous and convex in y, and decreasing in x. The convexity condition is important to ensure that the distance function displays diminishing marginal rates of technical substitution among outputs. Varian (1992) also indicates that monotonicity is an appropriate assumption for production sets and in our analysis it is ensured by the non-decreasing in y and decreasing in x properties.

To empirically estimate an ODF it is necessary to specify an algebraic form to describe the relationship between inputs and outputs. In particular, we use the standard flexible translog (TL) functional form which can be written as follows:

$$\begin{aligned}\ln D_{oi} = \beta_0 &+ \sum_{m=1}^{M}\beta_m \ln y_{mi} + 0.5\sum_{m=1}^{M}\sum_{n=1}^{M}\beta_{mn}\ln y_{mi}\ln y_{ni} + \sum_{m=1}^{M}\beta_{tm} t \ln y_{mi}\\ &+ \sum_{k=1}^{K}\beta_k \ln x_{ki} + 0.5\sum_{k=1}^{K}\sum_{l=1}^{K}\beta_{kl}\ln x_{ki}\ln x_{li}\\ &+ \sum_{k=1}^{K}\beta_{tk} t\ln x_{ki} + \sum_{k=1}^{K}\sum_{m=1}^{M}\beta_{km}\ln x_{ki}\ln y_{mi}\end{aligned} \tag{2}$$

where y_{mi} and x_{ki} are, respectively, the production level of output m and the quantity of input k used by vessel i. In addition, we allow the rate of technical change to be non-constant and non-neutral by interacting time (t) with the first-order coefficients for inputs and outputs (Cuesta and Orea, 2002).

[4] This illustration ignores the random nature of the production process which is introduced later in this section.

To ensure that the distance function is well-behaved we impose homogeneity of degree 1 in outputs and symmetry. The homogeneity restriction is imposed by normalizing the function by an arbitrary output; and, $\beta_{mn} = \beta_{nm}$ and $\beta_{kl} = \beta_{lk}$ for symmetry (Coelli and Perelman, 1999). This transformation of Eq. (2) is reflected in the following equation:

$$\begin{aligned}\ln\left(\frac{D_{oi}}{y_{1i}}\right) = \beta_0 &+ \sum_{m=2}^{M}\beta_m \ln\left(\frac{y_{mi}}{y_{li}}\right) + 0.5\sum_{m=2}^{M}\sum_{n=2}^{M}\beta_{mn}\ln\left(\frac{y_{mi}}{y_{li}}\right)\ln\left(\frac{y_{ni}}{y_{li}}\right)\\ &+ \sum_{m=2}^{M}\beta_{tm} t\ln\left(\frac{y_{mi}}{y_{li}}\right) + \sum_{k=1}^{K}\beta_k \ln x_{ki} + 0.5\sum_{k=1}^{K}\sum_{l=1}^{K}\beta_{kl}\ln x_{ki}\ln x_{li}\\ &+ \sum_{k=1}^{K}\beta_{tk} t\ln x_{ki} + \sum_{k=1}^{K}\sum_{m=2}^{M}\beta_{km}\ln x_{ki}\ln\left(\frac{y_{mi}}{y_{li}}\right)\end{aligned} \tag{3}$$

Eq. (3) can be rewritten as:

$$\begin{aligned}-\ln y_{1i} = \beta_0 &+ \sum_{m=2}^{M}\beta_m \ln\left(\frac{y_{mi}}{y_{1i}}\right) + 0.5\sum_{m=2}^{M}\sum_{n=2}^{M}\beta_{mn}\ln\left(\frac{y_{mi}}{y_{1i}}\right)\ln\left(\frac{y_{ni}}{y_{1i}}\right)\\ &+ \sum_{m=2}^{M}\beta_{tm} t\ln\left(\frac{y_{mi}}{y_{1i}}\right) + \sum_{k=1}^{K}\beta_k \ln x_{ki} + 0.5\sum_{k=1}^{K}\sum_{l=1}^{K}\beta_{kl}\ln x_{ki}\ln x_{li}\\ &+ \sum_{k=1}^{K}\beta_{tk} t\ln x_{ki} + \sum_{k=1}^{K}\sum_{m=2}^{M}\beta_{km}\ln x_{ki}\ln\left(\frac{y_{mi}}{y_{1i}}\right) - \ln D_{oi}\end{aligned} \tag{4}$$

To introduce the notion of a stochastic frontier, as formulated by Aigner et al. (1977), into Eq. (4) it is necessary to define the distance from each observation to the frontier as inefficiency (i.e., $ln\mathrm{D}_{oi} = -u_i$) and add a random noise variable (v_i) into the model. Consequently, the normalized TL output-oriented stochastic distance frontier (OSDF) function can be rewritten as:

$$\begin{aligned}-\ln y_{1i} = \beta_0 &+ \sum_{m=2}^{M}\beta_m \ln\left(\frac{y_{mi}}{y_{1i}}\right) + 0.5\sum_{m=2}^{M}\sum_{n=2}^{M}\beta_{mn}\\ &\times \ln\left(\frac{y_{mi}}{y_{1i}}\right)\ln\left(\frac{y_{ni}}{y_{1i}}\right) + \sum_{m=2}^{M}\beta_{tm} t\ln\left(\frac{y_{mi}}{y_{1i}}\right) + \sum_{k=1}^{K}\beta_k \ln x_{ki}\\ &+ 0.5\sum_{k=1}^{K}\sum_{l=1}^{K}\beta_{kl}\ln x_{ki}\ln x_{li} + \sum_{k=1}^{K}\beta_{tk} t\ln x_{ki} + \sum_{k=1}^{K}\sum_{m=2}^{M}\beta_{km}\\ &\times \ln x_{ki}\ln\left(\frac{y_{mi}}{y_{1i}}\right) + \sum_{j=1}^{J}\beta_j C_j + v_i + u_i\end{aligned} \tag{5}$$

where v_i, is assumed to be an independent and identically distributed normal random variable with 0 mean and constant variance, iid [N∼(0, σ_v^2)]. v_i is intended to capture random events, and its variance, σ_v^2, is a measure of the importance of random shocks in determining variation in output. Conversely, the inefficiency term u_i is non-negative and it is assumed to follow a half-normal distribution. Differences across vessels in the u_i are intended to capture differences in skill or efficiency (Alvarez and Schmidt, 2006). The model also includes a set of control variables (C) to account for extraneous factors affecting production. To facilitate the interpretation of the parameters, in the estimation of our model we transformed the left side of the equation to be ln y_1 rather than −ln y_1 as suggested by Coelli and Perelman (1999). By doing so, the interpretation of the parameters is now comparable to those from standard production function models.

TE scores can be computed using the following formula:

$$TE_i = D_{oi} = E(\exp(-u_i)|v_i - u_i) \tag{6}$$

Finally, following Caudill et al. (1995) we evaluate the determinants of inefficiency using a multiplicative heteroscedasticity framework such that:

$$\sigma_{ui} = \sigma_u \exp(Z_{mi};\omega) \tag{7}$$

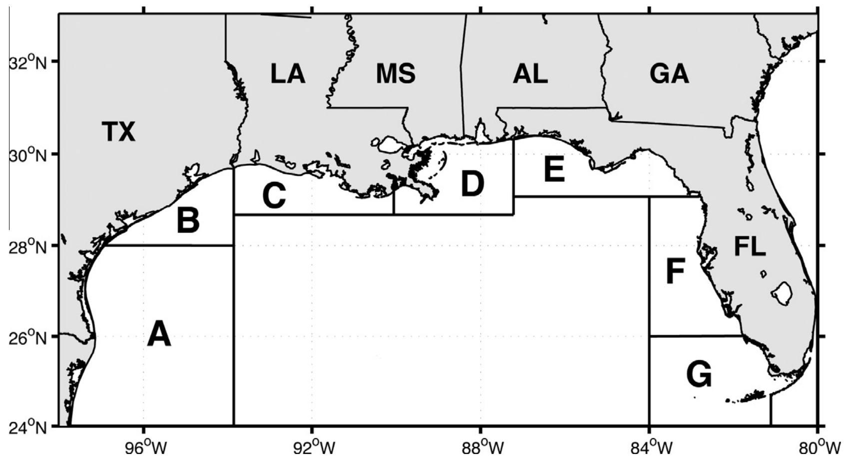

Fig. 2. Fishing zones.

where Z_{mi} is a vector of variables that explain inefficiency and ω are unknown parameters. Given that the inefficiency is assumed to follow a half-normal distribution, a decrease in the variance of the inefficiency term, u, will lead to an increase in mean efficiency levels. Hence, a positive coefficient indicates a negative relation with TE. Within this framework the parameters of the inefficiency model and production frontier are estimated jointly using maximum likelihood (ML) estimators.

Data and model specification

The data used in this study were derived from the National Marine Fisheries Service (NMFS) Southeast Coastal Fisheries Logbook Program and the Permits Information Management Systems (PIMS) databases. The logbook database contains trip-level information on dates of departure and offloading, landing sites, landings by species, catch disposition, gear characteristics and usage, fishing effort, crew size, dealer name, and fishing grounds, and the PIMS database contains information on vessel characteristics such as vessel length, engine propulsion and tonnage. After combining these databases and deleting observations from vessels that caught less than one hundred pounds of red snapper in federal waters in a given year, we obtained an unbalanced panel dataset that had a total of 81,702 observations on 912 distinct vessels for a 10 year span (2002–2011). To avoid biases due to heterogeneous production we separated the sample into vertical line and bottom longline trips and deleted observations from vessels that used multiple gears in a single trip.[5] Thus, the final data set contained 75,670 observations on 899 individual vessels.

The specification of the OSDF model includes four outputs, three inputs and a set of control variables. We aggregated trip-level harvests into four species or species groups: red snapper (y_1); other snappers (y_2); shallow water grouper (SWG, y_3); and, a residual or miscellaneous species (y_4).[6] In this model output levels were measured in pounds (gutted weight) and red snapper landings (y_1) were used to normalize the OSDF and impose linear homogeneity in outputs. Based on the literature and data availability our empirical model includes the following production inputs: crew size (x_1), number of fishing days (x_2), and vessel length (x_3). A similar input mix can be found in Orea et al. (2005) and Felthoven et al. (2009).

The model specification also includes control variables to account for regulatory and environmental factors affecting production. We control for the impact of regulations on the production process by including dummy variables for the red snapper seasonal closures (*CRS*), designed to protect and rebuild the red snapper resource and to extend its fishing season, and for the SWG closure (*CSWG*), gag spawning aggregation closure (*CGS*), and the Edges closure (*CE*), directed at protecting and rebuilding grouper species particularly gag. Additionally, we included a dummy variable, *CT*, to control for the emergency closure of the West Florida shelf to protect sea turtles in 2009 which prohibited the use of bottom longline gear. In addition, a dummy variable for the IFQ program is also included. The *IFQ* variable took a value of 1 after the implementation of the new regime (i.e., 2007–2011).

Alvarez and Schmidt (2006) and Solís et al. (2013) found that poor weather conditions can adversely impact fishing activities.[7] Therefore, we introduced a low pressure dummy variable (*mbar*) to control for the disruptive effects of passing fronts. This variable was set equal to 1 when the atmospheric pressure fell below 1005 millibars.

Felthoven and Morrison Paul (2004) argue that variations in stock size influence catch rates, thus, we included the spawning biomass index for red snapper (*stock*) to control for these changes. Annual biomass estimates for the areas east and west of the Mississippi river were obtained from the Sustainable Fisheries Division, Southeast Fisheries Science Center, NMFS.

We also used quarterly dummy variables (*season*) to account for interannual changes in fish abundance, and environmental and technological conditions. A similar approach can be found in Alvarez and Schmidt (2006).[8] Additionally, regional dummies variables were included to account for productivity differences among fishing grounds. Fig. 2 shows the location of these fishing grounds.

In the inefficiency model we included a dummy variable for the adoption of the IFQ program, a variable to account for crowding effects and a time trend. We modeled the effect of crowding using the number of commercial vessels fishing at the same day and

[5] In the resource economic literature researchers have addressed the issue of production heterogeneity (i.e., the presence of different technologies in a sample) by splitting the studied sample using either 'expert-knowledge' (Dupont et al., 2002; Tzouvelekas et al., 2001), which was the selected method for this study, or by using statistical techniques like cluster analysis (Alvarez et al., 2008) or latent class models (Alvarez and del Corral, 2010; Felthoven et al., 2009).

[6] Orea et al. (2005) describe the conditions under which one can aggregate over species in the specification of the empirical model.

[7] In addition, Solís and Letson (2013), among others, argue that the omission of climatic conditions when estimating production models could lead to biased estimates.

[8] The model includes 40 quarterly dummy variables, one for each quarter in the studied period. The first two quarters in 2002 were defined as the base level.

Table 1
Trip-level descriptive statistics.

Variable	Unit	Parameter	Vertical line		Bottom longline	
			Mean	S.D.	Mean	S.D.
Red snapper (RS)	*lbs/trip*	*y1*	492.20	992.86	164.04	563.17
Other snappers	*lbs/trip*	*y2*	354.58	870.71	83.12	385.59
SWG	*lbs/trip*	*y3*	354.94	654.14	2,393.32	2706.59
Miscellaneous species	*lbs/trip*	*y4*	250.66	745.75	1,466.64	2332.84
Crew size	*crew/trip*	*x1*	2.68	1.20	3.23	0.91
Fishing days	*days/trip*	*x2*	3.40	2.68	8.14	4.32
Vessel length	*feet*	*x3*	38.25	9.98	46.34	8.11
Closure RS	*Binary*	*CRS*	0.27	–	0.46	–
Closure gag spawn	*Binary*	*CGS*	0.06	–	0.06	–
Closure the Edges	*Binary*	*CE*	0.03	–	0.03	–
Closure SWG	*Binary*	*CSWG*	0.31	–	0.28	–
Emergency closure	*Binary*	*CT*	0.04	–	0.01	–
Low pressure	*Binary*	*mbar*	0.01	–	0.02	–
RS stock	*Log*	*stock*	13.08	–	12.84	–
South TX	*Binary*	*Area A*	0.02	–	0.06	–
North TX	*Binary*	*Area B*	0.09	–	0.02	–
LA	*Binary*	*Area C*	0.10	–	0.04	–
MS and AL	*Binary*	*Area D*	0.24	–	0.05	–
Northwest FL	*Binary*	*Area E*	0.33	–	0.15	–
Central West FL	*Binary*	*Area F*	0.19	–	0.59	––
Southwest FL	*Binary*	*Area G*	0.02	–	0.10	–
IFQ	*Binary*	*IFQ*	0.36	–	0.33	–
Crowding	*Count*	*CR*	20.49	13.41	15.88	9.76
No. Observations			64,494		11,176	

location (*CR*). Traditionally, negative crowding externalities are expected as a result of congestion on the fishing grounds. Thus, to better capture the effect of crowding on technical inefficiency (TI), the fishing grounds discussed earlier were further disaggregated into finer sub-areas. Appendix 1 presents the total number of vessels fishing in each of the fishing zones per year during the studied period.

Table 1 shows trip-level descriptive statistics by gear type. This table shows that, in general, bottom longline vessels are larger, take longer trips and are less dependent on red snapper than their vertical line counterparts. Fig. 3 shows the evolution of the quotas and landings for red snapper during the studied period.

Results and discussion

Model performance and characteristics of the technology

Table 2 presents ML estimates for the OSDF and technical inefficiency models for both the vertical line and bottom longline fleets.[9] We selected a TL functional form since preliminary analyses based on generalized likelihood ratio tests rejected the Cobb–Douglas specification in favor of the more flexible one. In addition, and following common practice, all variables in the TL models were normalized by their geometric mean (GM). In general, the estimated parameters from both fleets showed similar signs but their magnitudes differed. A log-likelihood ratio test for equality confirmed that both fleets had different technologies (*P*-value < 0.000), which justified the estimation of gear specific OSDFs.[10]

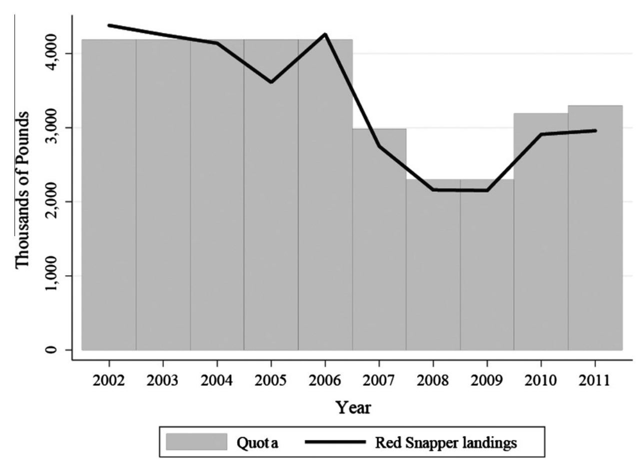

Fig. 3. Evolution of quotas and landings for red snapper.

The parameters for λ, the ratio of the standard error of u to that of v, are statistically significant at the 1% level with estimated values of 3.84 and 1.94 for the vertical line and bottom longline fleets, respectively. These results suggest that for both fleets, skill (efficiency) is more important than random shocks in explaining differences in landing levels across vessels. Specifically, the relative contribution of skill to the total variance of landing levels (γ) is equal to 0.94 and 0.79 for vessels employing vertical lines and bottom longlines, respectively. This implies that most of the variation in harvest levels not accounted by physical characteristics can be

[9] An anonymous referee raised his/her concern about the potential presence of sample selection bias in the data. To address this issue we re-estimated our model using the sample-selection correction method for stochastic production frontiers introduced by Greene (2010). To estimate this model, the following covariates where included in the sample selection equation: total trip revenue, share of RS to the total catch and age of the vessel. The specification of the OSDF model is the same as the one described in the main text. The results of this analysis reveal that the coefficient for ρ (the variable which captures the presence or absence of selectivity bias) is not statistically significant. The estimated coefficient for ρ was 0.194 and its standard error was 1.173 (*P*-value equals to 0.869). Consequently, there is no statistical support for self-selection bias in our data, and the traditional stochastic frontier framework offers unbiased estimates for our analysis.

[10] Specifically, the estimated LR test is: $LR = 2^*(lnL_P - (lnL_V + lnL_L))$ where lnL_P, lnL_V and lnL_L represent the log-likelihood function obtained from the pooled model, and the vertical line and bottom longline subsamples (restricted models), respectively (Bravo-Ureta et al., 2012).

Table 2
Parameter estimates of the stochastic distance frontier model by gear-type.

Parameter [a,b]	Vertical line		Longline	
	Coefficient	SE	Coefficient	SE
Frontier				
Constant	5.262***	0.210	−2.336**	0.928
Y_2	−0.111***	0.003	−0.077***	0.005
Y_3	−0.349***	0.002	−0.412***	0.005
Y_4	−0.164***	0.003	−0.345***	0.004
$Y_2^*Y_2$	−0.050***	0.001	0.009***	0.001
$Y_3^*Y_3$	−0.078***	0.000	−0.070***	0.001
$Y_4^*Y_4$	−0.071***	0.001	−0.056***	0.001
$Y_2^*Y_3$	0.022***	0.000	0.008***	0.001
$Y_2^*Y_4$	0.015***	0.000	0.000	0.001
$Y_3^*Y_4$	0.031***	0.000	0.058***	0.001
x_1	0.572***	0.023	0.147**	0.061
x_2	0.960***	0.015	0.695***	0.026
x_3	1.083***	0.044	0.622***	0.098
$x_1^*x_1$	−0.406***	0.039	−0.163*	0.094
$x_2^*x_2$	−0.478***	0.020	0.075***	0.028
$x_3^*x_3$	−0.422***	0.127	−0.361	0.433
$x_1^*x_2$	−0.167***	0.018	−0.026	0.044
$x_1^*x_3$	0.049	0.058	0.057	0.180
$x_2^*x_3$	−0.343***	0.039	0.331***	0.079
$Y_2^*x_1$	0.020***	0.004	−0.010	0.010
$Y_2^*x_2$	−0.035***	0.002	0.019***	0.005
$Y_2^*x_3$	0.043***	0.007	0.030*	0.017
$Y_3^*x_1$	−0.015***	0.003	0.018**	0.008
$Y_3^*x_2$	−0.006***	0.002	−0.026***	0.003
$Y_3^*x_3$	−0.010*	0.005	−0.058***	0.013
$Y_4^*x_1$	0.032***	0.003	0.019***	0.007
$Y_4^*x_2$	0.023***	0.002	−0.078***	0.003
$Y_4^*x_3$	−0.029***	0.007	0.047***	0.011
$Y2^*t$	−0.006***	0.001	0.000	0.001
$Y3^*t$	−0.007***	0.000	−0.005***	0.001
$Y4^*t$	−0.007***	0.000	−0.004***	0.001
x_1^*t	0.013***	0.004	0.040***	0.011
x_2^*t	0.038***	0.003	0.016***	0.005
x_3^*t	−0.049***	0.008	0.019	0.019
Area B	0.269***	0.036	−0.049	0.083
Area C	0.419***	0.036	0.210***	0.072
Area D	−0.037	0.037	0.067	0.100
Area E	0.165***	0.040	−0.044	0.110
Area F	−0.092**	0.042	0.097	0.111
Area G	−0.146***	0.049	−0.501***	0.113
CRS	−0.822***	0.017	−0.270***	0.021
CGS	−0.222***	0.022	−0.387***	0.033
CE	−0.128***	0.039	−0.180***	0.066
CSWG	−0.373***	0.039	−0.243***	0.072
CT	−0.016	0.040	−0.280***	0.083
mbar	−0.040	0.039	−0.093*	0.051
stock	0.063***	0.015	0.320***	0.067
IFQ	−0.409***	0.061	−0.387***	0.129
Inefficiency model				
Constant	1.915***	0.069	5.402***	0.172
CR	−0.175***	0.013	0.502***	0.036
IFQ	−0.170***	0.043	−0.765***	0.094
t	0.001	0.007	0.037**	0.017
σ_u	2.650***		0.880***	
σ_v	0.690***		0.454***	
$\lambda = \sigma_u/\sigma_v$	3.840***		1.938***	
$\gamma = \sigma_u^2/(\sigma_u^2 + \sigma_v^2)$	0.937***		0.790***	
Log-Likelihood	−95,810		−12,435	
No. of observations	64,494		11,176	

* $P < 0.10$; ** $P < 0.05$; *** $P < 0.01$.
[a] To impose linear homogeneity in outputs the RHS outputs are normalized by red snapper (e.g., $Y_2 = y_2/y_1$).
[b] Coefficients for 38 quarterly dummies have been excluded due to space limitations. However they are available from the lead author upon request.

attributed to differences in TE rather than to random shocks. Similar results can be found in Grafton et al. (2000) and Kompas and Che (2005). In addition, the null hypothesis that inefficiency does not exist (H_o: $\lambda = 0$) is rejected. Thus, the estimation of a production frontier is more appropriate than the estimation of a standard production function because TI exists in the fishery.

All elasticities exhibit the expected signs at the GM indicating that the estimated OSDFs satisfy the property of monotonicity at the GM (i.e., non-decreasing in outputs and decreasing in inputs). The coefficients for the different species (i.e., y_2, y_3 and y_4) were all negative and statistically significant, implying that as factors of production increase so do output levels.

Table 3 presents the partial distance elasticities and returns to scale (RTS) for both fleets for the entire 10 year period and for the 5 years before and after the implementation of the red snapper IFQ program. At the sample mean, the partial input distance elasticities for vertical line and bottom longline vessels are, respectively, 0.63 and 0.33 for crew, 1.14 and 0.77 for fishing days and 0.85 and 0.71 for vessel length. These results suggest that, *ceteris paribus*, a 10% increase in fishing time could increase aggregate landings by 11.4% and 7.7% for vertical liners and longliners, respectively. Therefore, given the quasi-fixed nature of capital, total landings can be increased proportionally more by extending the duration of the fishing trip rather than by increasing the size of the crew. The results also suggest that, on average, larger vessels are more productive than smaller ones. Herrero and Pascoe (2003)

Table 3
Partial distance elaticities and RTS before and after the implementation of the IFQs.

Elasticities	Vertical line				Longline			
	Whole sample	Pre IFQ	Post IFQ	Test of means[a]	Whole sample	Pre IFQ	Post IFQ	Test of means
y_1	−0.36	−0.38	−0.31	0.00	−0.12	−0.15	−0.08	0.00
y_2	−0.12	−0.11	−0.13	0.00	−0.07	−0.08	−0.06	0.00
y_3	−0.36	−0.32	−0.41	0.00	−0.44	−0.41	−0.49	0.00
y_4	−0.17	−0.18	−0.15	0.00	−0.36	−0.36	−0.36	0.70
x_1	0.63	0.65	0.62	0.00	0.33	0.27	0.45	0.00
x_2	1.14	1.20	1.07	0.00	0.77	0.74	0.82	0.00
x_3	0.85	0.98	0.63	0.00	0.71	0.65	0.83	0.00
RTS	2.62	2.74	2.42	0.00	1.80	1.66	2.09	0.00

[a] Test (P−values) for elasticities and RTS before and after the implementation of the IFQs.

Table 4
ME of the various closures.

	Vertical line	Longline
CRS	−0.56***	−0.24***
CGS	−0.20***	−0.32***
CE	−0.12***	−0.16***
CSWG	−0.31***	−0.22***
CT	−0.02	−0.24***

* $P < 0.10$; ** $P < 0.05$; *** $P < 0.01$.

Table 5
TE levels by subgroups of vessels before and after IFQs.

Subgroups	Vertical line			Longline		
	Pre IFQ	Post IFQ	Test of means[a]	Pre IFQ	Post IFQ	Test of means
All	0.394	0.414	0.012	0.510	0.567	0.002
Stay	0.432	0.425	0.452	0.530	0.577	0.020
Exit	0.371	–	–	0.482	–	–
Class 1	0.414	0.432	0.086	0.468	0.555	0.007
Class 2	0.379	0.407	0.023	0.543	0.579	0.085

[a] P-value.

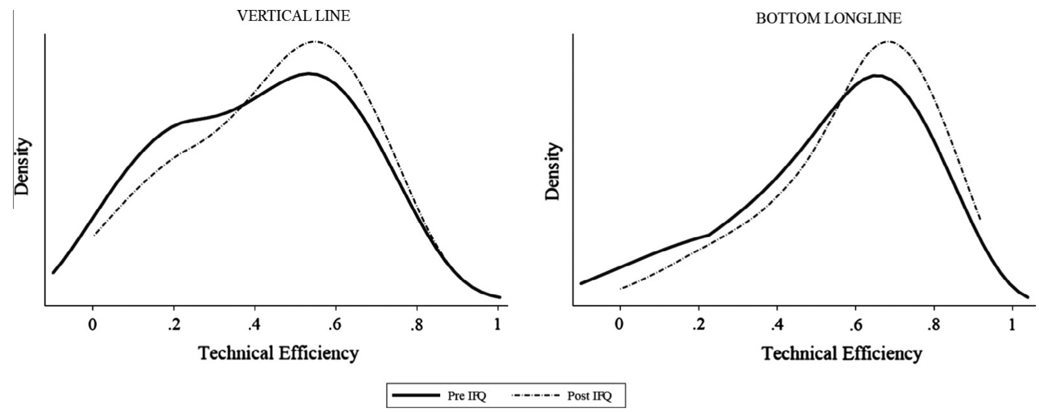

Fig. 4. Kernel distributions of TE estimates for the vertical line and longline fleet.

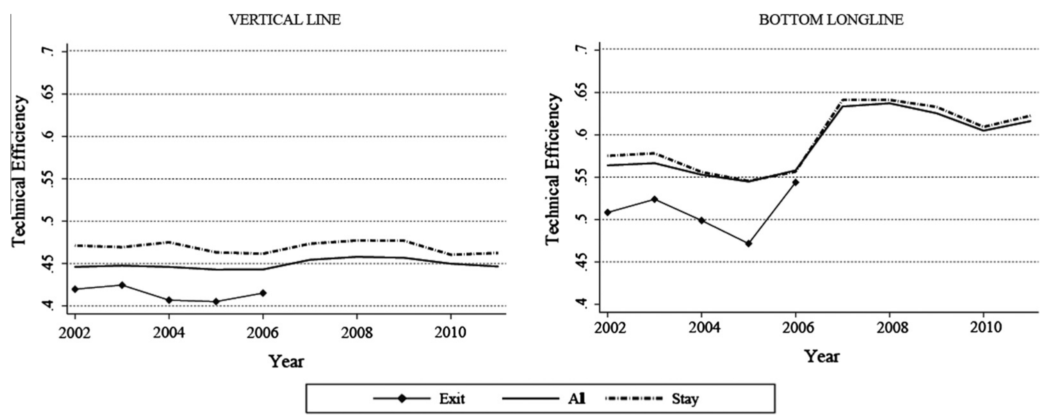

Fig. 5. TE scores for various segments of the vertical line and longline fleet, 2002–2011.

explain that bigger vessels have larger holds which can keep larger amounts of fish.

Table 3 also shows the impact of the IFQ program on the above partial distance elasticities. Vessels employing vertical lines display statistically significant decreases in all their partial distance input elasticities following the implementation of the IFQ program. Noteworthy, is the significant decrease in the magnitude of the fishing days variable, which is the result of vertical line vessels taking longer fishing trips and landing more fish which left them with little leeway to further increase production. Agar et al. (in press) using 5 year pre and post IFQ averages (2002–2006 vs. 2007–2011) report that landings volume and trip duration for the vertical line fleet increased by 81% (1297–2350 lbs.) and 68% (2.4–4 days), respectively. Table 3 also reveals changes in output distance elasticities before and after the adoption of the IFQ program. Output distance elasticities capture, for the most part, the share of each output to the total output produced. Our results show that the adoption of IFQs resulted in a more diverse landings mix. For example, vertical line vessels began targeting more vermilion snapper and red grouper. This change in targeting behavior can be explained not only by the freedom to adjust the timing, scale, and scope of their harvesting activities but also by quota cutbacks, which forced vessels owners to seek alternative target species to employ otherwise idle capital and labor.

At the sample mean, the RTS are equal to 2.62 and 1.80 for vertical line and bottom longline vessels, respectively. Asche et al. (2009) argue that increasing RTS can be explained by the presence of substantial overcapacity. In addition, Grafton et al. (2000) argue that the presence of increasing RTS offers potential cost savings to those operators that are able to freely adjust their vessel size. Similar results are reported by Bjørndal and Gordon (2000) and Felthoven et al. (2009). Notably, the IFQ program had opposite effects on the RTS of the fleets. Vertical line vessels showed a 12% decrease in their RTS (from 2.74 to 2.42) probably due to declining harvesting costs as less efficient vessels exited the fishery and the easing of harvest restrictions (i.e., trip limits and harvesting windows). In contrast, vessels using bottom longliners showed a 26% increase in their RTS (from 1.66 to 2.09) which is likely due to a pulse of new entrants many with limited red snapper allocation (i.e., leased quota) following the adoption of the grouper tilefish IFQ program in 2010.

The estimated parameter associated with the regulatory closures (i.e., *CRS*, *CGS*, *CE*, *CSWG and CT*) were negative and statistically significant suggesting that these regulations were effective at curtailing aggregate landings. Following Alvarez and Schmidt (2006) we estimated the marginal effect (ME) of each closure.[11] The ME metric measures the percentage change in the aggregate landings due to a specific closure. Table 4 shows ME estimates for the various closures. In general, the magnitudes and signs conform to our expectations. For example, the red snapper closure had a greater impact on the vertical line fleet than on the bottom longline fleet. Specifically, this closure decreased aggregate harvest levels of vertical line and bottom longline vessels by 56% and 24%, respectively. This difference is explained by the fact that vessels that use vertical lines are more dependent on red snapper than those that

[11] $ME = e^{\hat{\theta}} - 1$, where e is the natural logarithm and $\hat{\theta}$ is the estimated coefficient of each closure.

employ bottom longlines (Table 1). Conversely, longline vessels are more adversely impacted by grouper closures since red groupers, other SWG and deep-water groupers comprise the majority of their landings. As expected, the CT closure, which prohibited the use of bottom longlines is statistically significant only for the bottom longline fleet. The estimated coefficients for the IFQ program are negative and statistically significant for both fleets. These results suggest that, *ceteris paribus*, the adoption of the IFQ program has been an effective tool to reduce total landings in the red snapper fishery.[12]

The parameter estimates for the low-pressure dummies were negative for both fleet types but only statistically significant for the bottom longline fleet (Table 2). As expected, these results suggest that, *ceteris paribus*, aggregate harvest levels decrease in poor weather conditions. The difference in the statistical significance can be explained by the fact that bottom longline vessels may be more susceptible to bad weather because they tend to take longer trips and fish further offshore. On the other hand, vertical line vessels tend to take shorter trips and fish closer to shore so they can better plan to avoid operating in rough seas.

All parameter estimates associated with the regional dummy variables were statistically significant, suggesting that the productivity of the fishing grounds varies considerably. Vertical line and bottom longline vessels fishing in federal waters off the coast of the State of Louisiana showed the highest level of productivity of the sample. In contrast, fishing vessels operating in the federal waters off the southwest coast of Florida were the least productive.

The estimates of the TI model are presented at the end of Table 2. Following common practice, the interpretation of the parameter estimates is conducted relative to TE, that is, they are analyzed as if they displayed the opposite sign. The crowding variable which measured the number of vessels operating in the same fishing ground at the same time (*CR*) exhibited opposite effects on TE depending on the gear type. The estimated parameters suggest that crowding adversely impacts the TE of bottom longline vessels but favorably impacts the TE of vertical line vessels. This difference can be explained by the fact that the operation of bottom longline vessels is more susceptible to disruption because of the need to tend the gear sometimes for miles whereas vertical line operators fish directly off the boat. Pascoe et al. (2012) suggest that crowding dummies may be positive if fishers share information. These authors argue that the presence of multiple vessels increases the total area searched and the amount of information collected. This is a plausible result because the red snapper fishery is highly concentrated. About 5% of the shareholders own about 60% of the shares. Many of these large shareholders own multiple vertical line vessels (Agar et al., in press).

The results also show that time (t) had no significant impact on the efficiency of vertical liners, and a very small negative effect on the bottom longline fleet. Finally, the implementation of the IFQ program had a positive and statistically significant impact on the TE of the vertical line and bottom longline fleets. The following section presents a detailed analysis of the impact of IFQs on the TE, structure and characteristics of the red snapper fleet.

The effect of IFQs on the TE and composition of the fleet

Average TE scores before and after the implementation of the IFQ program are presented in Table 5. This table shows that IFQs had a positive effect on the TE of both fleets. Following the adoption of the IFQ program, TE scores for the representative vertical line vessel increased by nearly 5% from 0.39 to 0.41, whereas the TE score for the representative bottom longline vessel increased by 11% from 0.51 to 0.57. In addition, Fig. 4 shows that the kernel distribution of TE scores narrowed and median values increased after the IFQ program, especially among longline vessels.

Brandt (2007) and Pascoe et al. (2012) argue that efficiency gains achieved by IFQs are derived from vessel level improvements and re-structuring of the composition of the fleet. To explore this issue in more detail, we further partition the fleet into the following subgroups: (1) all active vessels (All); (2) vessels that continued to harvest in the fishery after the IFQ program (Stay); and (3) vessels that left after the IFQ program (Exit). Fig. 5 shows the evolution of TE scores for three categories of vessels. Vessels that remained in the red snapper fishery were always the most technically efficient in the sample. Conversely, those vessels that left after the IFQs were always the less technically efficient relative to the other categories. Fig. 6 which compares TE scores prior to the IFQ program (2002–2006) for the Stay and Exit subsamples, confirms that vessels with lower TE levels left the red snapper fishery after the IFQ program. It is important to notice that this figure also shows an overlap between the two groups (i.e., Stay and Exit), especially among vertical line vessels, which indicate that efficient vessels also left the fleet and some inefficient vessels are still active. A similar trend can be found in Pascoe et al. (2012).

Table 5 corroborates that the remaining vessels are more efficient than those who exited the red snapper fishery. The remaining vessels are 14% and 9% more efficient than exiting vertical line vessels and bottom longline vessels, respectively. The same table shows that the increase in TE was statistically significant for the remaining bottom longline fleet, which increased, on average, by 10%. We speculate that the increased TE was partly driven by the culling of the longline fleet due to a bottom longline endorsement requirement. To qualify for the endorsement bottom longline vessels had to demonstrate an annual average harvest of 40,000 lb of reef fish during 1999–2007. The endorsement program was put in place to reduce endangered sea turtle interactions with bottom longline gear. However, no significant changes in TE were found for the remaining vertical line subgroup after the IFQs.

Table 5 also tracks the effect of IFQs on the average level of TE for different subgroups of vessels. As indicated, previous to the implementation of the IFQ program, fishing privileges were allocated based on their landing history. There were two trip limit endorsements available for the red snapper fleet: Class 1 (2000 lbs. trip limit) and Class 2 (200 lbs. trip limit). Table 5 shows that vessels with Class 1 endorsements had the largest impact on their TE with increments of 4% and 19% for vertical liners and bottom longliners, respectively. Vessels with Class 2 endorsements also display positive effects on their TE, with an increase of 7% for vertical line vessels and 7% for longline vessels. These results suggest

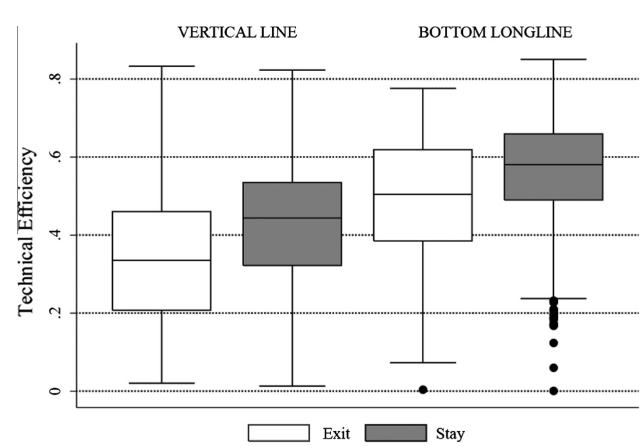

Fig. 6. Distribution of TE scores prior to IFQ (2002–2006) of vessels that stayed and exited the fleet after its implementation.

[12] The impact of the IFQ program on the total factor productivity and fishing capacity of the GOM red snapper fishery clearly deserves further research.

that relaxation of harvest windows and trips had a positive impact on the harvesting efficiency of the fleet. Furthermore, the dedicated red snapper fleet (i.e., Class 1 vessels) received a larger share of the quota which provided them with added flexibility.

Summary and conclusions

Overcapacity and declining fish stocks are serious issues facing fishery managers around the world. IFQs have become a popular tool to solve these problems because they foster sound incentives that advance environmental stewardship and the rational use of capital and labor. This study examined the impact of the implementation of the IFQ program on the TE, production characteristics and composition of the red snapper fleet in the US Gulf of Mexico. We implemented an OSDF model using trip level data for 899 individual vessels from 2002 to 2011 (5 years before and after the IFQ program).

The analysis showed that the IFQ program had a positive effect on the TE of the vertical line and longline fleets. This result is driven by changes in the industry composition and, to a lesser extent, by vessel level efficiency gains. We found that, on average, those vessels with low TE scores exited the fishery, whereas those that remained marginally increased their TE scores. The empirical results also show significant changes in input and output distance elasticities after the adoption of the IFQ program. Changing output distance elasticities are of particular interest to fishery managers because they may signal that tighter regulations may be required for those species jointly harvested with red snapper. In the Gulf of Mexico, there is growing concern about the health of the vermilion snapper stocks because fishers are said to be targeting them partly to establish a catch history so that they can stake a claim in this fishery should it became part of an IFQ program. In other words, improved management in one fishery may require better management for others, especially when fishers expect to benefit from future regulatory changes.

Our analysis also found that the magnitude of the RTS declined for the majority of the vessels (vertical line fleet), suggesting that IFQs resulted in cost savings by allowing fishing firms to freely adjust their input and output mix. However, the magnitude of the RTS for the remaining fleets is still high, implying that they have not yet found their economically optimal configuration despite their ability to purchase and/or lease quota. Consequently, further policy interventions may be required to re-structure the fleet. Pascoe et al. (2012) suggest that combining IFQs with a buyback program expedites the achievement of an economically optimal fleet configuration because buybacks can directly influence sunk costs, which are a key reason for fishers delaying capital retirement decisions.

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The views and opinions expressed or implied in this article are those of the authors and do not necessarily reflect the position of the National Marine Fisheries Service, NOAA.

Appendix A

See Table A1.

Table A1
Number of vessels fishing in the same subzone, 2002–2011.

Fishing zone	Year									
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
A_1	43	52	58	45	40	36	27	18	27	19
A_2	29	33	36	29	28	19	16	12	11	12
B_1	13	14	19	17	17	9	6	7	10	7
B_2	20	16	17	13	9	7	7	5	5	5
B_3	3	5	3	1	1	0	0	0	0	0
B_4	0	1	3	1	2	0	0	0	0	0
B_5	1	1	2	0	0	0	0	0	0	0
C_1	31	30	29	25	20	13	15	21	11	10
C_2	48	47	41	28	27	21	4	16	15	11
C_3	45	44	35	21	15	14	15	17	14	7
C_4	42	41	48	45	39	21	11	8	12	11
D_1	71	72	72	63	56	47	42	57	55	50
D_2	64	69	58	50	55	40	44	54	45	36
D_3	9	10	15	5	8	6	3	7	0	2
D_4	47	50	42	45	33	26	31	24	23	19
E_1	144	128	139	129	134	119	126	110	88	73
E_2	101	101	113	107	95	92	88	89	82	77
E_3	67	76	67	65	56	52	49	67	46	41
F_1	96	104	96	82	86	84	80	80	75	74
F_2	138	142	142	131	132	108	107	114	107	96
F_3	161	159	157	165	163	145	140	135	103	85
G_1	22	27	28	25	23	25	20	19	15	16
G_2	48	48	54	46	47	43	29	33	26	38
G_3	43	43	42	47	49	43	36	39	28	38
G_4	1	0	0	0	0	0	0	0	0	0

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