Evaluating the Impact of Individual Fishing Quota Management on Vessel Technical Efficiency in the Gulf of Mexico Grouper-Tilefish Commercial Fishery

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Methods and Procedures

Stochastic distance function (SDF) were used to estimate production efficiency of commercial fishing vessels in the Gulf of Mexico reef fish fishery. The impact of the implementation of the individual fishing quota (IFQ) system on fleet efficiency was assessed. Previous literature has shown commercial fishing to be characterized by substantial variability in production due to random factors and fishing operation cannot readily adjust production accordingly (Solis et al. 2014a). Stochastic frontier analysis (SFA) is a parametric approach to analyzing the production efficiency of commercial fishing operations and is the preferred methodology since uncertainly is accounted for in the empirical model. Commercial fishing is a multi-species venture where inputs are often similar and common between targeted species. An output-oriented SDF was adopted to evaluate the production efficiency in a multioutput framework. Following Kumbhakar, Wang, and Horncastle (2015), the multioutput distance function (ODF) for the SFA model is expressed as:

(1) $$D_0(y,x) = min\{\theta|(y/\theta)\ \epsilon\ \rho(x)\}$$

where $\rho(x)$ is a set of feasible output vectors for each input vector x. If $D_0(y,x) \leq 1$, then (x,y) belongs to $\rho(x)$, and if $D_0(y,x) = 1$ then y lies on the production possibility frontier.

The empirical relationship between inputs and outputs is estimated using a translog functional form based on the results of a generalized likelihood ratio test compared to the Cobb-Douglas specification. The model is specified as follows:

(2)
$$lnD_{0i} = \beta_0 + \sum_{m=1}^{M} \beta_m lny_{mi} + 0.5\sum_{m=1}^{M}\sum_{n=1}^{M} \beta_{mn} lny_{mi} lny_{ni} + \sum_{l=1}^{L} \beta_l lnx_{li} + 0.5\sum_{l=1}^{L}\sum_{k=1}^{L} \beta_{lk} lnx_{li} lnx_{ki} + \sum_{l=1}^{L}\sum_{m=1}^{M} \beta_{lm} lnx_{li} lny_{mi}$$

where y_{mi} and x_{li} represent the quantity of output m and input l for vessel $i = 1,2,3, \dots n$, respectively. The following conditions were imposed to ensure the ODF is well-behaved: (1) homogeneity of degree one in outputs, and (2) symmetry of the parameters. Homogeneity was imposed by normalizing the function by an arbitrary output (Coellli and Perelman 1999) and symmetry of the parameters by setting $\beta_{mn} = \beta_{nm}$. In addition, all input and output variables (y_{ji} and x_{ji}) were normalized by their geometric mean. Equation 2 is then re-specified as:

(3)

$$ln\frac{D_{0i}}{y_{1i}} = \beta_0 + \sum_{m=1}^{M}\beta_m ln\left(\frac{y_{mi}}{y_{1i}}\right) + 0.5\sum_{m=1}^{M}\sum_{n=1}^{M}\beta_{mn} ln\left(\frac{y_{mi}}{y_{1i}}\right) ln\left(\frac{y_{ni}}{y_{1i}}\right) + \sum_{l=1}^{L}\beta_l lnx_{li} + 0.5\sum_{l=1}^{L}\sum_{k=1}^{L}\beta_{lk} lnx_{li} lnx_{ki} + \sum_{l=1}^{L}\sum_{m=1}^{M}\beta_{lm} lnx_{li} ln\left(\frac{y_{mi}}{y_{1i}}\right)$$

Equation 3 can be rewritten as:

(4)

$$-lny_{1i} = \beta_0 + \sum_{m=1}^{M}\beta_m ln\left(\frac{y_{mi}}{y_{1i}}\right) + 0.5\sum_{m=1}^{M}\sum_{n=1}^{M}\beta_{mn} ln\left(\frac{y_{mi}}{y_{1i}}\right) ln\left(\frac{y_{ni}}{y_{1i}}\right) + \sum_{l=1}^{L}\beta_l lnx_{li} + 0.5\sum_{l=1}^{L}\sum_{k=1}^{L}\beta_{lk} lnx_{li} lnx_{ki} + \sum_{l=1}^{L}\sum_{m=1}^{M}\beta_{lm} lnx_{li} ln\left(\frac{y_{mi}}{y_{1i}}\right) - lnD_{0i}$$

Substituting $-\mathrm{lnD}_{0\mathrm{i}} = -\mathrm{u}_\mathrm{i}$ introduces the stochastic frontier into the model and captures the effects of inefficiency in the production process. An error term is added to account for random disturbances and denoted by v_i. The estimated output-oriented stochastic distance function is specified as:

(5)

$$lny_{1i} = \beta_0 + \sum_{m=1}^{M}\beta_m ln\left(\frac{y_{mi}}{y_{1i}}\right) + 0.5\sum_{m=1}^{M}\sum_{n=1}^{M}\beta_{mn} ln\left(\frac{y_{mi}}{y_{1i}}\right) ln\left(\frac{y_{ni}}{y_{1i}}\right) + \sum_{l=1}^{L}\beta_l lnx_{li} + 0.5\sum_{l=1}^{L}\sum_{k=1}^{L}\beta_{lk} lnx_{li} lnx_{ki} + \sum_{l=1}^{L}\sum_{m=1}^{M}\beta_{lm} lnx_{li} ln\left(\frac{y_{mi}}{y_{1i}}\right) + \sum_{j=1}^{J}\beta_j C_j + v_i + u_i$$

where $\mathrm{v}_\mathrm{i}$is random error term, u_i captures differences in efficiency, and $\mathrm{C}_\mathrm{j}$is a set of control variables designed to account for external factors affecting vessel production.[1] External factors include changes in management, stock levels, fishing area, and temporal changes in efficiency due to technology change. The SDFs were calculated using trip level observations. In addition, the technical inefficiency component (μ) was assumed to be heteroskedastic and with variance (σ_μ) a function of IFQ implementation (the inefficiency model).

Following the estimation of the output-oriented stochastic distance function, vessel level technical efficiency scores were calculated by averaging trip-level technical efficiency scores for

[1] The left side of the equation was transformed from $-lny_{1i}$to lny_{1i} as outlined in Coelli and Perelman (1999) for ease of parameter interpretation.

each vessel. Technical efficiency scores were then compared in two different ways to assess the impact of IFQ implementation on fleet performance. First pre-IFQ TE scores were compared between vessels that left the fishery prior to IFQ implementation ("Exit") and vessels that stayed in the fishery ("Stay"). This analysis evaluated potential gains in technical efficiency due to less efficient vessels leaving the fishery upon IFQ implementation. Next pre and post-IFQ TE scores were compared for those vessels that stayed in the fishery following IFQ implementation ("Stay") to examine the effects of regime shift on fleet efficiency. Technical efficiency scores were calculated as follows:

(7) $$TE_i = E[exp(-u_i)|v_i - u_i]$$

Technical efficiency scores are bounded between 0 and 1 with a score of 1 indicating that a vessel lies on the production frontier is producing the maximum amount of inputs given its inputs.

TE Data and Model Specification

TE Data

National Marine Fisheries Service Logbook data were used to perform the technical efficiency analysis. The data includes trip-level information on landings, fishing effort, and vessel characteristics. The data used covered the period from 2004 to August 2015 and included all Gulf of Mexico. The data used was bounded to the six years prior to implementation of the Grouper-Tilefish IFQ program (2004-2009) and approximately the six years after (2010 to August 2015). Observations with missing data on landings or inputs were removed from the data set.

Models were run for red grouper (RG), gag grouper (GAG), other shallow water grouper (OSWG), deep-water groupers (DWG), and tilefish (TF) for long line fishers and RG, GAG, and OSWG for vertical line fishers[2]. For all models, only trips by vessels that harvested at least 100 pounds of the IFQ species group being analyzed during the year of the trip were included in the analysis[3].

TE Model Specification

The empirical models each included four outputs, three inputs, and a set of control variables. The four outputs were specified as trip landings with the species composition varying by model as outlined in Table 1. Output levels were measured in pounds gutted weight.

[2] Since very few vertical line fishers target DWG and TF these species-angler pairings were not analyzed.
[3] Since 2015 data was only available through the end of August, the annual catch requirement for 2015 was only 67 pounds of the IFQ species being analyzed.

Table 1. Output variables in the production frontier models

Output	RG	GAG	Model OSWG	DWG	TF
y1	Red Grouper	Gag Grouper	Black Grouper + Scamp + Yellowfin Grouper + Yellowmouth Grouper	Deep Water Group – Misty Grouper – Queen Snapper	Golden Tilefish + Goldface Tilefish + Blueline Tilefish
y2	Gag Grouper + Other Shallow Water Grouper	Red Grouper + Other Shallow Water Grouper	SWG (including Gag and Red Grouper) – OSWG	Tilefish + Misty Grouper + Queen Snapper	Other Tilefish + Deep Water Groupers
y3	Mid Depth Snappers + Shallow Water Snappers	Mid Depth Snappers + Shallow Water Snappers	Mid Depth Snappers + Shallow Water Snappers	Shallow Water Groupers + Mid Depth Snappers + Shallow Water Snappers	Shallow Water Groupers + Mid Depth Snappers + Shallow Water Snappers
y4	All Other Landings	All Other Landings	All other landings	All other landings	All other landings

Note: For each model, the y1 variable was used to impose homogeneity.

The three input variables were: crew (x1), number of fishing days (x2), and vessel length (x3). Both the input and output variables were interacted with a monthly time variable (ty2, ty3, ty4, tx1, tx2, tx3) allowing for time-varying technical change, similar to Cuesta and Orea (2002).

The control variables included varied based on the fishing type (longline or vertical line) and are shown in Table 2. The BIOMASS variable was included to account for the potential impacts of stock abundance of commercially important reef fish species[4]. REGION was included to account for differences in production based on fishing grounds. The four closure variables (RS CLOSURE, GROUPER CLOSURE, LONGLINE CLOSURE, and TURTLE CLOSURE) were included to account for differences in production that could have been due to regulatory closures of certain fisheries and fishing grounds. The LONGLINE and TURTLE closures were specific to the longline fishery and, as such, were not included as control variables in the vertical line analysis. Trip level descriptive statistics for the vertical line and longline analyses are presented in Tables 3 and 4, respectively.

Table 2. Control variable used in the production frontier models.

Variable	Description	Longline	Vertical Line
IFQ	Dummy variable. Equal to one if trip occured after IFQ implementation.	X	X
Biomass	Sum of NMFS estimated biomass of: red snapper, red grouper, gag grouper, vermillion snapper.	X	X
Weather	Dummy variable. Equal to one if atmospheric pressure was below 1005mb in the fishing region during any part of the fishing trip.	X	X
Region	Dummy variable for trip fishing area (see Figure 1).	X	X
Season	Dummy variable for month trip occurred in.	X	X
RS Closure	Dummy variable, =1 if red snapper fishery was closed during the trip (seasonal closures were in effect prior to RS IFQ program - before 2007).	X	X
Grouper Closure	Dummy variable, =1 if gag, red, and black grouper fisheries were closed during the trip (seasonal closures were used prior to Grouper/Tilefish IFQ program - before 2010).	X	X

[4] Ideally all IFQ species biomass data would have been included but data was not available for all species for the entire period analyzed.

Longline Closure	The Eastern Gulf Bottom Longline Closure was implemented in 2010 and closed the Gulf of Mexico east of 85'30 to bottom longline fishing for three months (June-August). Longline trips taken during the closure by vessels that fished the closed area during other parts of the year were deemed to be effected. Dummy variable = 1 if a trip was effected.	X
Turtle Closure	The Turtle Closure was implemented in 2009 (5/18/2009-10/28/2009) in an effort to limit turtle bycatch by longline vessels. Longline trips taken during the closure by vessels that fished the closed area during other parts of the year were deemed to be effected. Dummy variable = 1 if a trip was effected.	X

Figure 1. Map of fishing areas used in stochastic production frontier analysis

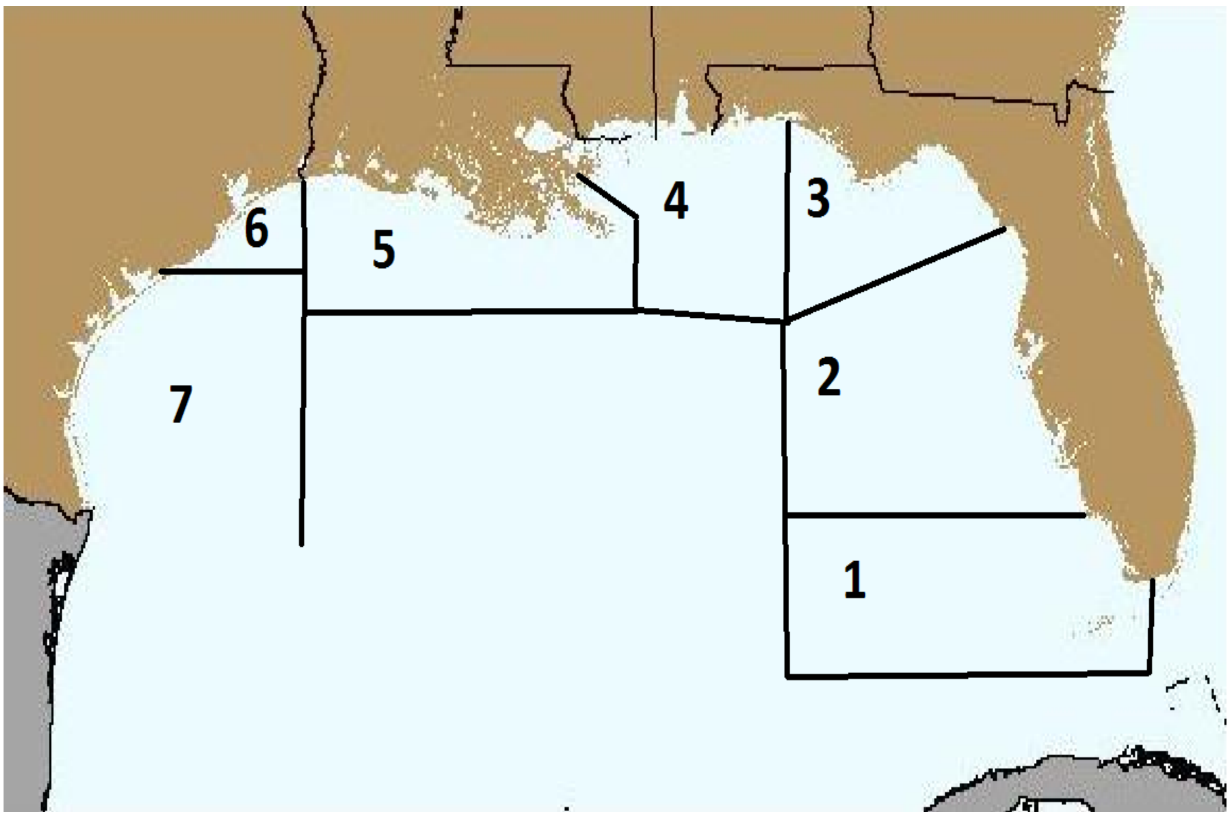

Table 3. Descriptive statistics for the variables used in the SDFs (vertical line fleet)

		MODEL					
		RG		GAG		OSWG	
Variable	Units	Mean	SD	Mean	SD	Mean	SD
y1	lbs	361.20	601.23	136.11	322.72	64.11	195.62
y2	lbs	12.34	91.69	86.71	317.43	147.46	435.60
y3	lbs	171.00	691.18	315.94	994.04	381.73	1,067.98
y4	lbs	107.22	436.84	128.85	456.20	130.85	491.89
Crew	crew	2.34	0.99	2.47	1.08	2.68	1.18
Fishing Days	days	3.89	2.89	3.99	2.89	4.29	2.92
Vessel Length	feet	36.23	7.51	37.16	8.14	39.43	8.59
IFQ	dummy	0.37		0.36	-	0.33	-
Biomass	tons	38.35	0.87	38.38	0.87	38.40	0.87
Weather	dummy	0.01	-	0.01	-	0.01	-
Area:	dummy						
1 (FL Keys)		0.12	-	0.04	-	0.13	-
2 (SW FL)		0.37	-	0.35	-	0.25	-
3 (FL Big Bend)		0.40	-	0.40	-	0.27	-
4 (FL Panhandle - AL-MS)		0.09	-	0.09	-	0.12	-
5 (LA)		0.02	-	0.09	-	0.13	-
6 (SE. TX)		<0.01	-	0.02	-	0.08	-
7 (S. TX)		<0.01	-	<0.01		0.01	-
Season:	dummy						
January		0.08	-	0.08	-	0.08	-
February		0.07	-	0.07	-	0.08	-
March		0.08	-	0.08	-	0.09	-
April		0.10	-	0.10	-	0.09	-
May		0.10	-	0.10	-	0.09	-
June		0.10	-	0.09	-	0.09	-
July		0.10	-	0.10	-	0.10	-
August		0.09	-	0.09	-	0.08	-
September		0.07	-	0.07	-	0.07	-
October		0.07	-	0.08	-	0.07	-
November		0.06	-	0.07	-	0.07	-
Decebmer		0.08	-	0.08	-	0.09	-
RS Closure	dummy	0.20	-	0.19	-	0.19	-
Grouper Closure	dummy	0.03	-	0.03	-	0.05	-

Table 4. Descriptive statistics for the variables used in the SDFs (longline fleet)

		MODEL									
		RG		GAG		OSWG		DWG		TF	
Variable	Units	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
y1	Lbs	2,633.50	2,745.75	330.03	631.67	190.38	420.90	908.21	1,784.77	603.78	2,377.40
y2	Lbs	24.77	248.27	404.31	1,315.77	503.50	1,462.90	80.85	1,596.15	189.31	795.18
y3	Lbs	39.30	303.72	81.06	422.85	87.68	408.73	1,860.39	2,588.92	2,064.26	2,693.19
y4	Lbs	756.72	2,328.21	796.70	2,456.72	774.29	2,340.39	269.39	837.49	297.68	858.34
Crew	crew	3.20	0.78	3.25	0.77	3.30	0.86	3.32	0.87	3.36	0.90
Fishing Days	Days	8.87	4.17	9.03	4.16	8.75	4.23	8.79	4.32	8.68	4.35
Vessel Length	Feet	45.80	6.99	46.09	7.11	46.71	7.82	47.00	7.69	47.46	7.90
IFQ	dummy	0.29		0.31		0.29		0.29		0.25	
Biomass	tons	38.18	0.87	38.23	0.88	38.23	0.88	38.24	0.89	38.20	0.86
Weather	dummy	0.03	-	0.03	-	0.03	-	0.03	-	0.03	-
Area:	dummy										
1 (FL Keys)		0.14	-	0.12	-	0.13	-	0.13	-	0.13	-
2 (SW FL)		0.68	-	0.69	-	0.63	-	0.57	-	0.51	-
3 (FL Big Bend)		0.13	-	0.13	-	0.12	-	0.16	-	0.18	-
4 (FL Panhandle - AL-MS)		0.02	-	0.02	-	0.02	-	0.04	-	0.04	-
5 (LA)		0.01	-	0.02	-	0.03	-	0.04	-	0.05	-
6 (SE. TX)		0.00	-	0.01	-	0.01	-	0.01	-	0.02	-
7 (S. TX)		0.02	-	0.03	-	0.05	-	0.06	-	0.07	-
Season:	dummy										
January		0.10	-	0.10	-	0.10	-	0.10	-	0.10	-
February		0.09	-	0.09	-	0.09	-	0.09	-	0.09	-

March		0.09	-	0.09	-	0.09	-	0.10	-	0.10	-
April		0.10	-	0.10	-	0.10	-	0.10	-	0.10	-
May		0.10	-	0.10	-	0.10	-	0.10	-	0.10	-
June		0.08	-	0.08	-	0.08	-	0.08	-	0.08	-
July		0.09	-	0.08	-	0.09	-	0.08	-	0.08	-
August		0.07	-	0.07	-	0.07	-	0.07	-	0.07	-
September		0.08	-	0.08	-	0.08	-	0.07	-	0.07	-
October		0.08	-	0.08	-	0.08	-	0.07	-	0.07	-
November		0.06	-	0.06	-	0.06	-	0.06	-	0.06	-
Decebmer		0.06	-	0.06	-	0.06	-	0.06	-	0.06	-
RS Closure	dummy	0.30	-	0.28	-	0.29	-	0.28	-	0.28	-
Grouper Closure	dummy	0.04	-	0.04	-	0.05	-	0.06	-	0.06	-
Longline Closure	dummy	0.05	-	0.06	-	0.05	-	0.06	-	0.05	-
Turtle Closure	dummy	0.01	-	0.01	-	0.01	-	0.01	-	0.01	-

Results

Stochastic Distance Frontier Estimates

The parameter estimates from the stochastic production frontier models and associated inefficiency models are presented in Appendices I (vertical line) and II (longline). Parameter estimates of the first-order terms (ly2, ly3, ly4, lx1, lx2, and lx3) have the expected sign for all models demonstrating monotonicity at the geometric mean, that is, non-decreasing in outputs and decreasing in inputs in accordance with economic theory. The statistical significance of the λ estimate for all models indicates that technical inefficiency is present and validates the use of a production frontier rather than a production function. In addition, the fact that the λs are greater than one for all models indicates that skill is more important than random shocks in explaining production variation across vessels (Solís et al. 2014b). The γ values measure the amount of total variance in landings due to skill and vary across models from a low of 0.662 to a high of 0.867.

By normalizing by the geometric mean and summing the parameter coefficients on the input variables (lx1, lx2, and lx3) we are able to measure returns to scale (Coelli et al. 2005). The returns to scale are above one for every model run indicating increasing returns to scale. Increasing returns to scale have previously been found in similar analysis on fisheries (Solís et al. 2014b; Felthoven et al. 2009). Asche et al. (2009) argued that increasing returns to scale can be caused by overcapacity in the fishing fleet. The parameter estimates on the fishing area variables indicate that fishing productivity generally varies by fishing area. The parameters for IFQ were all positive indicating that IFQ management led to increases in landings. In addition, the biomass parameter was positive for all SDFs except tilefish (longline) indicating that greater biomass led to increased landings all else equal.

While the grouper closure negatively impacted landings for both the longline and vertical line fleets, the red snapper closure actually had a positive effect on longline vessel landings. The red snapper closures positive effect on longline landings is likely due to the fact that longliners generally do not target red snapper, during the study period longliners accounted for approximately 33% of total landings but only 5% of red snapper landings. The turtle closure negatively impacted longline landings as would be expected but the longline closure had mixed effects. For the shallow water grouper models (RG, GAG, and OSWG), landings were negatively impacted but not statistically significantly so. However, the longline closure positively impacted longliner landings in the deep water grouper and tilefish models. This finding seems reasonable given that fishing for deep water grouper and tilefish usually occurs in deeper water and targeting of these species may have been increased during the longline closures. The technical inefficiency model results indicate that implementation of the IFQ program led to increased efficiency (the negative coefficient on the parameter value indicates that inefficiency decreased).

In the next subsection we cover the vessel level TE scores and how they were impacted by IFQ management.

Technical Efficiency Scores

TE scores were estimated for each fishing trip and then averages were calculated at the vessel level. This analysis looks at two facets of how IFQ management changed the fishery. First, we compare pre-IFQ TE scores for those vessels that left the fishery prior to IFQ management to those vessels that continued fishing after IFQ management was implemented. It seems plausible that more technically efficient vessels might place a higher value on quota than their less efficient counterparts and buy them out of a rationalized fishery. In addition, fleet owners might be expected to use only their more efficient vessels when harvesting grouper and tilefish after IFQ implementation given that the race to fish is removed. If that were the case we would expect those vessels that stayed in the fishery to have been the more efficient vessels. Second, we examine how IFQ management effected vessel level efficiency; namely, did fishers harvest more efficiently during the IFQ period when the race to fish was removed.

Table 5 compares the pre-IFQ TE scores of the vessels that stayed in the fishery to those that exited the fishery prior to IFQ management. The vessels that continued fishing after IFQ management were, on average, more technically efficient than the vessels that exited the fishery prior to IFQ implementation. Table 6 evaluates how the TE scores of vessels that remained in the fishery changed following IFQ implementation. On average, vessel TE scores rose following IFQ implementation for the vessels that continued to take part in the fishery. TE scores rose post IFQ implementation across all models, with average increases ranging from 2.37% (OSWG vertical line) to 13.61% (OSWG longline).

Table 5. Pre-IFQ TE Scores (Stayed. Vs. Exited)

	Vertical line fishers						Difference in Means
		Stayed			Exited		Stayed TE - Exited TE
Species Group	**Obs.**	**Mean TE**	**SE**	**Obs.**	**Mean TE**	**SE**	**Pr(|T|>|t|)**
Red Grouper	323	0.487	0.005	491	0.451	0.006	0.000
Gag Grouper	281	0.502	0.006	432	0.448	0.006	0.000
Other Shallow Water Grouper	215	0.507	0.006	421	0.459	0.006	0.000

	Longline fishers						Difference in Means
		Stayed			Exited		Stayed TE - Exited TE
Species Group	**Obs.**	**Mean TE**	**SE**	**Obs.**	**Mean TE**	**SE**	**Pr(|T|>|t|)**
Red Grouper	74	0.511	0.011	105	0.448	0.013	0.001
Gag Grouper	74	0.535	0.010	81	0.472	0.013	0.000
Other Shallow Water Grouper	74	0.507	0.011	103	0.454	0.012	0.002
Deep Water Grouper	73	0.518	0.010	94	0.485	0.012	0.039
Tilefish	73	0.538	0.009	94	0.509	0.011	0.053

Table 6. Vessel level TE Scores (Pre Vs. Post IFQ)

Vertical line fishers						Difference in Means
		Pre-IFQ		Post-IFQ		Post - Pre IFQ
Species Group	**Obs.**	**Mean TE**	**SE**	**Mean TE**	**SE**	**Pr(|T|>|t|)**
Red Grouper	323	0.487	0.005	0.502	0.006	0.005
Gag Grouper	281	0.502	0.006	0.523	0.006	0.000
Other Shallow Water Grouper	215	0.507	0.006	0.519	0.008	0.093

Longline fishers						Difference in Means
		Pre-IFQ		Post-IFQ		Post - Pre IFQ
Species Group	**Obs.**	**Mean TE**	**SE**	**Mean TE**	**SE**	**Pr(|T|>|t|)**
Red Grouper	74	0.511	0.011	0.540	0.013	0.025
Gag Grouper	74	0.535	0.010	0.588	0.010	0.000
Other Shallow Water Grouper	74	0.507	0.011	0.576	0.011	0.000
Deep Water Grouper	73	0.518	0.010	0.573	0.011	0.000
Tilefish	73	0.538	0.009	0.590	0.010	0.000

Appendix I – Stochastic distance frontier parameter estimates – vertical line fishers

	RG			GAG			OSWG		
Variable	Coef.	SE	P	Coef.	SE	P	Coef.	SE	P
Constant	0.375	0.333	0.261	0.429	0.319	0.179	-0.093	0.317	0.769
lY2	-0.193	0.004	0.000	-0.334	0.004	0.000	-0.328	0.004	0.000
lY3	-0.510	0.004	0.000	-0.392	0.004	0.000	-0.423	0.004	0.000
lY4	-0.342	0.004	0.000	-0.220	0.004	0.000	-0.136	0.004	0.000
lx1 (Crew)	0.812	0.024	0.000	0.666	0.026	0.000	0.498	0.028	0.000
lx2 (Fishing days)	0.945	0.014	0.000	0.619	0.015	0.000	0.488	0.015	0.000
lx3 (Vessel Length)	0.999	0.049	0.000	0.282	0.056	0.000	0.350	0.057	0.000
lyy22	-0.054	0.001	0.000	-0.108	0.001	0.000	-0.079	0.001	0.000
lyy23	0.040	0.001	0.000	0.098	0.001	0.000	0.101	0.001	0.000
lyy24	0.001	0.002	0.345	0.062	0.001	0.000	0.061	0.001	0.000
lyy33	-0.095	0.001	0.000	-0.093	0.001	0.000	-0.110	0.001	0.000
lyy34	0.068	0.001	0.000	0.069	0.001	0.000	0.096	0.001	0.000
lyy44	-0.058	0.001	0.000	-0.062	0.001	0.000	-0.068	0.001	0.000
tly2	-0.001	0.000	0.000	-0.001	0.000	0.000	-0.001	0.000	0.000
tly3	0.001	0.000	0.000	0.001	0.000	0.000	0.002	0.000	0.000
tly4	-0.001	0.000	0.000	-0.001	0.000	0.000	-0.002	0.000	0.000
lx11	-0.304	0.032	0.000	-0.321	0.033	0.000	-0.087	0.035	0.014
lx12	0.260	0.026	0.000	0.066	0.028	0.020	-0.059	0.027	0.031
lx13	-0.050	0.110	0.648	0.356	0.117	0.002	0.422	0.116	0.000
lx22	-0.456	0.014	0.000	-0.365	0.015	0.000	-0.407	0.015	0.000
lx23	0.165	0.061	0.007	-0.176	0.066	0.008	-0.259	0.062	0.000
lx33	-0.467	0.129	0.000	-0.346	0.136	0.011	-1.133	0.153	0.000
tlx1	-0.003	0.001	0.000	-0.006	0.001	0.000	-0.003	0.001	0.000
tlx2	0.002	0.000	0.000	0.004	0.000	0.000	0.001	0.000	0.016
tlx3	0.009	0.002	0.000	0.011	0.002	0.000	0.012	0.002	0.000
lyx21	0.015	0.005	0.002	-0.014	0.005	0.002	-0.002	0.004	0.546
lyx22	0.023	0.003	0.000	-0.048	0.003	0.000	-0.023	0.002	0.000
lyx23	0.106	0.010	0.000	-0.073	0.010	0.000	-0.058	0.008	0.000
lyx31	0.001	0.004	0.733	-0.007	0.004	0.054	-0.016	0.004	0.000
lyx32	-0.021	0.002	0.000	-0.022	0.002	0.000	-0.042	0.002	0.000
lyx33	0.034	0.007	0.000	0.014	0.008	0.062	0.017	0.008	0.026
lyx41	0.023	0.003	0.000	0.021	0.004	0.000	-0.012	0.004	0.001
lyx42	0.025	0.002	0.000	0.021	0.002	0.000	-0.006	0.002	0.002
lyx43	-0.012	0.007	0.094	-0.012	0.008	0.121	-0.008	0.008	0.290
IFQ	0.072	0.017	0.000	0.055	0.018	0.002	0.043	0.018	0.020

	RG			GAG			OSWG		
Biomass	0.041	0.009	0.000	0.027	0.008	0.001	0.031	0.008	0.000
Weather	-0.151	0.033	0.000	-0.153	0.031	0.000	-0.152	0.030	0.000
Area									
2 (SW FL)	0.142	0.013	0.000	-0.016	0.018	0.381	0.281	0.014	0.000
3 (FL Big Bend)	0.284	0.013	0.000	0.070	0.018	0.000	0.436	0.014	0.000
4 (FL Panhandle - AL - MS)	0.245	0.018	0.000	-0.006	0.022	0.772	0.309	0.016	0.000
5 (LA)	0.103	0.028	0.000	0.201	0.024	0.000	0.448	0.018	0.000
6 (SE. TX)	-0.138	0.117	0.239	0.130	0.033	0.000	0.378	0.021	0.000
7 (S. TX)	-0.290	0.222	0.192	-0.049	0.068	0.469	0.384	0.034	0.000
Season									
February	-0.045	0.017	0.010	-0.045	0.018	0.012	-0.030	0.018	0.097
March	-0.124	0.017	0.000	-0.127	0.018	0.000	-0.072	0.018	0.000
April	-0.105	0.016	0.000	-0.129	0.017	0.000	-0.098	0.017	0.000
May	-0.042	0.016	0.009	-0.052	0.017	0.002	-0.075	0.017	0.000
June	-0.014	0.016	0.400	-0.010	0.017	0.545	-0.059	0.017	0.001
July	-0.084	0.016	0.000	-0.061	0.017	0.000	-0.113	0.017	0.000
August	-0.057	0.017	0.001	-0.040	0.017	0.019	-0.123	0.018	0.000
September	-0.055	0.017	0.001	-0.044	0.018	0.013	-0.132	0.018	0.000
October	-0.084	0.017	0.000	-0.082	0.018	0.000	-0.133	0.018	0.000
November	-0.078	0.018	0.000	-0.104	0.019	0.000	-0.163	0.019	0.000
December	-0.064	0.017	0.000	-0.096	0.018	0.000	-0.131	0.018	0.000
RS Closure	-0.070	0.011	0.000	-0.087	0.011	0.000	-0.115	0.011	0.000
Grouper Closure	-0.157	0.024	0.000	-0.226	0.025	0.000	-0.138	0.021	0.000
Inefficiency Model									
Constant	0.048	0.020	0.018	-0.003	0.022	0.909	-0.032	0.021	0.13
IFQ	-0.227	0.025	0.000	-0.348	0.028	0.000	-0.265	0.029	0.00
σ_μ	0.983		0.000	0.941		0.000	0.944		0.000
σ_v	0.530		0.000	0.531		0.000	0.510		0.000
$\lambda = \sigma_\mu/\sigma_v$	1.855		0.000	1.774		0.000	1.850		0.000
$\gamma = \sigma_\mu^2/(\sigma_\mu^2 + \sigma_v^2)$	0.775		0.000	0.759		0.000	0.774		0.000
Model Statistics:									
Log-likelihood	-61,750			-55,340			-50,630		
# of observations	52,544			44,971			44,604		

Notes: Right-hand-side outputs are normalized by y1 to impose linear homogeneity (e.g., Y2 = y2/y1).

Appendix II – Stochastic distance frontier parameter estimates – longline fishers

	RG			GAG			OSWG			DWG			TF		
Variable	Coef.	SE	P	Coef.	SE	P	Coef.	SE	P	Coef.	SE	P	Coef.	SE	P
Constant	0.764	0.584	0.191	-0.265	0.578	0.646	-0.503	0.578	0.384	-1.401	0.653	0.032	1.431	0.740	0.053
lY2	-0.078	0.008	0.000	-0.409	0.007	0.000	-0.432	0.007	0.000	-0.318	0.010	0.000	-0.232	0.007	0.000
lY3	-0.155	0.009	0.000	-0.094	0.008	0.000	-0.139	0.008	0.000	-0.698	0.006	0.000	-0.575	0.007	0.000
lY4	-0.864	0.005	0.000	-0.425	0.006	0.000	-0.407	0.006	0.000	-0.239	0.008	0.000	-0.195	0.009	0.000
lx1 (Crew)	0.221	0.079	0.005	0.223	0.083	0.007	0.048	0.080	0.550	0.394	0.086	0.000	0.247	0.083	0.003
lx2 (Fishing days)	0.724	0.033	0.000	0.542	0.034	0.000	0.585	0.034	0.000	0.836	0.040	0.000	0.613	0.037	0.000
lx3 (Vessel Length)	1.589	0.128	0.000	1.333	0.135	0.000	1.517	0.136	0.000	1.282	0.143	0.000	0.971	0.137	0.000
lyy22	-0.037	0.002	0.000	-0.098	0.002	0.000	-0.082	0.001	0.000	-0.047	0.002	0.000	-0.088	0.002	0.000
lyy23	0.023	0.003	0.000	0.035	0.003	0.000	0.020	0.002	0.000	0.022	0.002	0.000	0.071	0.002	0.000
lyy24	0.014	0.002	0.000	0.141	0.002	0.000	0.133	0.002	0.000	0.025	0.003	0.000	0.039	0.003	0.000
lyy33	-0.020	0.002	0.000	-0.024	0.002	0.000	-0.033	0.002	0.000	-0.088	0.001	0.000	-0.088	0.001	0.000
lyy34	0.009	0.002	0.000	0.024	0.002	0.000	0.041	0.002	0.000	0.090	0.002	0.000	0.087	0.002	0.000
lyy44	-0.077	0.001	0.000	-0.077	0.001	0.000	-0.083	0.001	0.000	-0.072	0.002	0.000	-0.071	0.002	0.000
tly2	-0.001	0.000	0.000	0.000	0.000	0.037	0.000	0.000	0.372	0.001	0.000	0.010	-0.001	0.000	0.024
tly3	0.001	0.000	0.000	0.001	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.002	0.001	0.000	0.000
tly4	-0.001	0.000	0.000	-0.001	0.000	0.000	-0.001	0.000	0.000	-0.001	0.000	0.004	-0.001	0.000	0.003
lx11	-0.345	0.092	0.000	-0.338	0.101	0.001	-0.208	0.098	0.034	-0.017	0.115	0.885	0.347	0.133	0.009
lx12	0.262	0.080	0.001	0.397	0.087	0.000	0.336	0.083	0.000	0.016	0.084	0.850	-0.089	0.095	0.349
lx13	0.138	0.358	0.700	0.091	0.400	0.819	-0.661	0.356	0.063	0.036	0.392	0.927	-0.747	0.451	0.098
lx22	-0.273	0.025	0.000	-0.217	0.027	0.000	-0.220	0.025	0.000	-0.153	0.028	0.000	-0.139	0.031	0.000
lx23	0.986	0.142	0.000	0.613	0.158	0.000	0.800	0.144	0.000	0.779	0.162	0.000	0.660	0.180	0.000
lx33	-1.588	0.416	0.000	-0.980	0.429	0.022	-0.903	0.432	0.036	0.070	0.470	0.882	-0.528	0.540	0.328
tlx1	0.012	0.002	0.000	0.007	0.002	0.001	0.010	0.002	0.000	0.003	0.002	0.240	0.001	0.003	0.620
tlx2	0.006	0.001	0.000	0.007	0.001	0.000	0.009	0.001	0.000	0.007	0.001	0.000	0.009	0.001	0.000
tlx3	-0.020	0.004	0.000	-0.017	0.004	0.000	-0.016	0.004	0.000	-0.008	0.004	0.048	-0.012	0.005	0.011

	RG			GAG			OSWG			DWG			TF		
lyx21	0.040	0.013	0.003	0.006	0.012	0.608	-0.015	0.010	0.133	0.030	0.012	0.011	-0.013	0.013	0.308
lyx22	-0.016	0.006	0.005	-0.051	0.005	0.000	-0.036	0.004	0.000	0.048	0.006	0.000	-0.008	0.006	0.162
lyx23	-0.012	0.024	0.625	-0.094	0.021	0.000	0.013	0.017	0.454	0.046	0.020	0.023	-0.046	0.023	0.040
lyx31	-0.025	0.012	0.040	-0.023	0.012	0.060	-0.045	0.011	0.000	-0.003	0.007	0.636	0.005	0.008	0.519
lyx32	0.097	0.005	0.000	0.091	0.004	0.000	0.085	0.004	0.000	-0.030	0.003	0.000	-0.028	0.003	0.000
lyx33	0.003	0.020	0.886	0.024	0.020	0.211	-0.009	0.017	0.580	-0.027	0.012	0.025	-0.018	0.014	0.181
lyx41	0.013	0.007	0.063	0.024	0.008	0.002	0.037	0.007	0.000	-0.019	0.009	0.039	-0.028	0.011	0.010
lyx42	-0.060	0.003	0.000	-0.071	0.003	0.000	-0.067	0.003	0.000	-0.003	0.004	0.513	0.002	0.005	0.685
lyx43	0.043	0.012	0.001	0.039	0.013	0.002	0.068	0.013	0.000	0.015	0.020	0.435	0.008	0.022	0.716
IFQ	0.157	0.036	0.000	0.135	0.035	0.000	0.134	0.036	0.000	0.091	0.042	0.029	0.117	0.049	0.016
Biomass	0.041	0.015	0.009	0.049	0.015	0.001	0.052	0.015	0.001	0.049	0.017	0.005	-0.008	0.020	0.679
Weather	-0.138	0.037	0.000	-0.159	0.036	0.000	-0.165	0.038	0.000	-0.181	0.041	0.000	-0.150	0.045	0.001
Area															
2 (SW FL)	-0.130	0.019	0.000	-0.148	0.020	0.000	-0.128	0.020	0.000	-0.134	0.022	0.000	-0.124	0.025	0.000
3 (FL Big Bend)	-0.242	0.025	0.000	-0.268	0.026	0.000	-0.241	0.026	0.000	-0.229	0.027	0.000	-0.222	0.030	0.000
4 (FL Panhandle - AL - MS)	-0.240	0.049	0.000	-0.211	0.048	0.000	-0.175	0.048	0.000	-0.123	0.046	0.008	-0.139	0.049	0.005
5 (LA)	-0.266	0.067	0.000	-0.210	0.054	0.000	-0.355	0.044	0.000	-0.079	0.043	0.067	-0.004	0.047	0.931
6 (SE. TX)	0.350	0.123	0.004	-0.163	0.083	0.050	-0.115	0.072	0.107	0.181	0.067	0.007	0.223	0.070	0.002
7 (S. TX)	0.118	0.084	0.163	-0.117	0.067	0.079	-0.135	0.058	0.020	0.183	0.050	0.000	0.227	0.053	0.000
Season															
February	-0.004	0.028	0.893	-0.027	0.028	0.327	-0.035	0.029	0.226	-0.009	0.033	0.775	-0.011	0.037	0.063
March	-0.046	0.028	0.098	-0.064	0.028	0.023	-0.051	0.029	0.079	-0.154	0.033	0.000	-0.165	0.037	-0.092
April	-0.095	0.027	0.000	-0.092	0.027	0.001	-0.085	0.028	0.002	-0.206	0.031	0.000	-0.210	0.035	-0.141
May	-0.056	0.026	0.033	-0.054	0.027	0.042	-0.032	0.027	0.236	-0.176	0.031	0.000	-0.167	0.035	-0.098
June	-0.092	0.030	0.002	-0.075	0.031	0.015	-0.070	0.031	0.025	-0.165	0.035	0.000	-0.165	0.039	-0.088
July	-0.041	0.029	0.157	-0.083	0.030	0.005	-0.065	0.030	0.030	-0.292	0.035	0.000	-0.276	0.040	-0.198

	RG			GAG			OSWG			DWG			TF		
August	-0.117	0.030	0.000	-0.122	0.031	0.000	-0.152	0.032	0.000	-0.383	0.036	0.000	-0.381	0.042	-0.299
September	-0.037	0.028	0.189	-0.089	0.028	0.002	-0.083	0.029	0.004	-0.274	0.034	0.000	-0.283	0.039	-0.206
October	-0.073	0.029	0.011	-0.097	0.029	0.001	-0.095	0.030	0.001	-0.326	0.034	0.000	-0.309	0.039	-0.232
November	-0.140	0.030	0.000	-0.154	0.030	0.000	-0.145	0.031	0.000	-0.290	0.036	0.000	-0.289	0.041	-0.209
December	-0.087	0.030	0.004	-0.078	0.030	0.010	-0.073	0.031	0.021	-0.248	0.036	0.000	-0.308	0.041	-0.228
RS Closure	0.064	0.017	0.000	0.042	0.017	0.015	0.029	0.017	0.102	0.015	0.019	0.436	0.038	0.021	0.072
Grouper Closure	-0.270	0.037	0.000	-0.308	0.037	0.000	-0.257	0.037	0.000	-0.138	0.038	0.000	-0.079	0.041	0.057
Longline Closure	-0.034	0.032	0.291	-0.053	0.032	0.093	-0.008	0.033	0.800	0.118	0.037	0.001	0.153	0.044	0.001
Turtle Closure	-0.241	0.069	0.001	-0.355	0.071	0.000	-0.295	0.074	0.000	-0.305	0.079	0.000	-0.412	0.087	0.000
Inefficiency Model															
Constant	0.029	0.030	0.328	-0.122	0.033	0.000	0.018	0.031	0.556	-0.173	0.050	0.001	-0.404	0.072	0.000
IFQ	-0.527	0.050	0.000	-0.660	0.057	0.000	-0.716	0.057	0.000	-0.588	0.076	0.000	-0.531	0.111	0.000
σ_μ	0.946		0.000	0.859		0.000	0.921		0.000	0.850		0.000	0.769		0.000
σ_v	0.370		0.000	0.390		0.000	0.409		0.000	0.499		0.000	0.549		0.000
$\lambda = \sigma_\mu/\sigma_v$	2.558		0.000	2.203		0.000	2.250		0.000	1.703		0.000	1.401		0.000
$\gamma = \sigma_\mu^2/(\sigma_\mu^2 + \sigma_v^2)$	0.867		0.000	0.829		0.000	0.835		0.000	0.744		0.000	0.662		0.000
Model Statistics:															
Log-likelihood		-11,150			-10,040			-11,520			-11,060			-9,029	
# of observations		11,181			10,471			11,296			10,326			8,342	

Notes: Right-hand-side outputs are normalized by y1 to impose linear homogeneity (e.g., Y2 = y2/y1).

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