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JEL Classification: Q2

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1 Introduction

Managers and industry in the eastern Gulf of Mexico commercial grouper fishery are currently crafting an individual fishing quota (IFQ) management program to replace the current controlled-access regulatory program which includes a license limitation, annual catch quotas for heavily targeted species, per trip catch limits, minimum size limits, area/gear restrictions, and season closures (see Amendment 29, Gulf of Mexico Fishery Management Council).[1,2] Market-based incentives implicit in IFQ management promise to increase economic performance for the commercial fleet, stabilize the economic and regulatory environment and improve safety for fishermen. Improved economic performance is expected as the fleet is downsized and harvesting responsibilities are consolidated onto fewer vessels, and the relatively productive vessels among the currently active reef fish fleet (Gulf of Mexico Fishery Management Council, 2007). The goal of this paper is to characterize changes in fleet structure, effort levels, and vessel-level harvesting and costs that are expected under the IFQ management program, and to estimate the economic gains that accompany these changes.

The conceptual approach follows work by Weninger and Waters (2003) and others.[3] The empirical model incorporates recent advances in the understanding of targeting behavior in multiple-species fisheries (Singh and Weninger, 2007). Data on trip-level harvesting and annual operating expenses for the 2005-06 fishing seasons are used to estimate a multiple species harvest cost function. The calibrated model is then used to characterize vessel-level harvesting activities, fleet size, revenues, costs and harvest permit prices that are expected under the proposed IFQ management program. The model also provides estimates of the cost savings from replacing the current controlled access management program with IFQs.

The analysis predicts significant fleet downsizing will occur in the grouper fishery under IFQ management. It is estimated that the accompanying economies of scale and redistribution of harvest to productive boats will result in variable cost savings in the range of \$2.226 million to \$3.236 million annually. Although more difficult to quantify, additional savings from vessel maintenance costs, docking fees, and utility expenditures are expected under the smaller IFQ-regime fleet.

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[1] Amendment 29 to the Fishery Management Plan for the Reef Fish Resources of the Gulf of Mexico considers the merits of several management alternatives, including the elimination of latent permits, a buyback or buyout program, permit endorsements, an individual fishing quota program, and an individual transferable effort quota program.

[2] Eight major grouper species are targeted in the eastern region of the Gulf of Mexico reef fish fishery: red, black, gag, scamp, yellowedge, warsaw and snowy groupers, and speckled hind.

[3] Weninger and Waters (2003) and Weninger (forthcoming) study the potential effects of adopting rights-based managment in the northern and eastern regions of the reef fish fishery. Dupont (2000), Squires and Kirkley (1995, 1996), and Squires, Alauddin and Kirkley (1994) provide *ex ante* estimates of the potential gains from tradable harvest permits. Studies examining the performance of existing programs are increasingly available, e.g., Grafton, Squires and Fox (2000).

The next section introduces a conceptual model of harvesting behavior and equilibrium fleet structure in a multiple-species fishery that is managed with IFQs. Section 3 describes the data and empirical methods used to estimate trip-level harvesting costs. Results of the estimation are presented in Section 4. Section 5 predicts vessel harvesting activity, equilibrium fleet structure, and revenues and costs expected in the IFQ-managed fishery. Concluding remarks follow in Section 6. Details for the econometric estimation are presented in an Appendix.

2 Conceptual Framework

Under IFQ management, tradable harvest permits, which sum to the target total harvest for each reef fish species, are distributed to fishermen. Target harvest levels are chosen by the fishery manager.[4] Let H_i denote the total allowable harvest for species $i = 1, ..., m$, and let h_i denote the quantity harvested by a representative vessel operation. With frictionless permit trading, a per period harvest permit lease prices λ_i will emerge. We will assume that active vessel operations purchase and sell permits with the goal of maximizing per-period profits, given as

$$\pi(r, w, k) = \max_{h \geq 0} \{rh - C(h, w, k, x)\};$$

$C(h, w, k, x)$ is the short run harvest cost function of the harvest vector h, factor input price vector w (e.g., fuel, bait, gear and labor), the capital endowment k (e.g., vessel, electronic equipment, skipper skill), and a vector stock abundance indexes, $x = (x_1, ..., x_m)$. Letting p denote the vector of dockside prices, the net price for landed fish in the above expression is $r = (p - \lambda)$, where λ is a vector of harvest permit rental prices. The capital endowment k conditions the costs of harvesting fish and thus differentiates vessel operations in terms of the harvesting cost incurred. We can index vessels by their capital type, and rank them from lowest to highest cost, $C(h, w, k_1, x) \leq C(h, w, k_2, x) \leq ....$ The equilibrium fleet structure under the IFQ management program is determined by the following conditions:

$$\textstyle\sum_{j=1}^{J^*} h_i^{k_j} = H_i \qquad i = 1, ..., m \tag{C1}$$

$$J^* = \arg\max_J \{\textstyle\sum_{j=1}^{J} ph^{k_j} - C(h^{k_j}, w, x, k_j)\}, \tag{C2}$$

where h^{k_j} is the harvest vector and quantity of harvest permits fished by vessel with capital k_j.

Conditions C1 and C2 simultaneously determine equilibrium harvest permit lease prices and the number of harvesting operations, denoted J^*, in the IFQ-managed fishery. Condition C1 states

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[4] Material in this section follows Weninger (forthcoming).

that for each species the total fleet catch must equal the allowable harvest, H_i (also the total permits issued by the manager). Condition C2 states that the J^* active vessel operations must attain the largest net harvesting profits, conditional on the aggregate harvest target $H_1, .., H_m$. C2 implies that active vessels will exhaust available economies of scale in production, and that most cost efficient operations will be active under the IFQ program. If this were not the case, gains from permit trading would exist, which contradicts the equilibrium condition. Also notice that C2 ensures that the maximum harvesting profits or resource rent is obtained from the total allowable harvest.[5]

We next turn to the problem of empirically estimating the harvest cost function $C(h, w, k_j, x)$ and characterizing the equilibrium fleet structure in the eastern Gulf reef fish fishery.

2.1 Empirical model

Reef fish fishermen intercept multiple species on a typical fishing trip. The harvest technology intrinsically embodies an economy of scope and produces a cost efficient harvest mix that depends on the absolute as well as the relative abundance of various reef fish species in the sea. Following Singh and Weninger (2007), we will assume that targeting activity entails additional costs that reef fish fishermen, in general, will prefer to avoid. Costly targeting can however be part of a profit maximizing harvesting strategy, if for example, species-specific prices vary and/or harvest permits are scarce for some reef fish species. We next introduce a functional form that can represent costly targeting behavior.

Let $\theta_i = \frac{h_i}{h_1 + ... + h_M}$ denote the quantity share of species i in the total harvest. The share of the species i stock on the fishing ground is denoted $\varphi_i = \frac{x_i}{x_1 + ... + x_M}$. *Trip-level* expenses are assumed to take the following form:

$$c(h, w, k, x) = \left[1 + \frac{1}{2} \sum_{i=1}^{M} \gamma_i \left(\theta_i - \varphi_i\right)^2\right] \cdot g(w, h, k|\beta). \tag{1}$$

The first bracketed term is the targeting component. The second term, $g(w, h, k|\beta)$, captures non-targeting costs.

The targeting component captures trip expenses that arise due to the targeting activities of the vessel. The model assumes there exists a particular harvest mix $\theta = \varphi$ that can be harvested without costly targeting. If the vessel skipper chooses this particular harvest mix, the term $\frac{1}{2} \sum_{i=1}^{m} \gamma_i \left(\theta_i - \varphi_i\right)^2 = 0$. Since no targeting activities are required, no *added* costs are incurred, and the trip costs are given by $g(w, h, k|\beta)$. We assume that $g(w, h, k|\beta)$ is an increasing and convex

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[5] A dynamic bioeconomic model would identify the resource rent maximizing values for $H_1, ..., H_m$ (see Singh and Weninger, 2007).

function of harvest h, an increasing and concave function of w and a non-increasing function of capital k. Note that if a fisherman chooses a harvest mix that differs from the cost-minimizing mix, i.e., $\theta_i \neq \varphi_i$, the first right-hand term will exceed unity and costs will increase.

The unknown parameters of the targeting component include $\gamma_i = (\gamma_1, ..., \gamma_m)$ and the vector of stock shares, $\varphi = (\varphi_1, ..., \varphi_m)$. The non-target component parameter vector is β. In principle data on species-specific stock abundance could be used, eliminating the need to estimate φ. Data limitations prevented such an approach here.[6]

While it is costly to target a species mix that differs from φ, targeting can be part of a profit maximizing fishing strategy. We assume that vessel skippers target a vector h that maximizes the trip profits. In deriving an expression for trip profits it is important to consider the role of the crew share system in the fishery. It is usually the case in commercial fisheries that the vessel captain and crew are paid a share of the trip revenues, or in some cases, a share of trip variable profits, i.e., revenue less some components of trip expenses. Captain and crew wages typically represent a significant component of the net revenues of a trip, and the method of labor remuneration has implications for profit maximizing harvest choices, which we assume are made by the vessel skipper (McConnell and Price, 2006). We will denote the residual share of trip revenue and variable costs that accrue to the vessel skipper as η_r and η_{vc}, respectively. The skipper's residual profits after labor costs are given as

$$\max_h \left\{ \eta_r p' h - \eta_{vc} c(w, h, k, x) \right\}.$$

Assuming an interior solution, the necessary conditions for profit maximization are

$$\eta p_i = c_i(w, h, k, x), \quad , i = 1, ..., m, \tag{2}$$

where $\eta = \eta_r / \eta_{vc}$, and $c_i(w, h, k, x) = \partial c(w, h, k, x)/\partial h_i$ denotes the marginal cost of harvesting species i fish. Hereafter, we will interpret and refer to the parameter $\eta = \eta_r / \eta_{vc}$ as the *skipper residual profit* parameter.

The trip level cost function in equation 1 and the first order necessary conditions in equation 2 form the basis for estimation of the unknown parameters (γ, φ, β) and the skipper residual profit parameter, η. The next section describes the data and estimation procedure.

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[6] Standard models of stock abundance utilize commercial catch data to varying degrees. It would seem unwise to use an estimate of abundance derived from commercial harvesting activity data to analyze the costs of harvesting fish.

3 Fishery Background and Data

The reef fish fishery in the eastern Gulf of Mexico is a complex of bottom-dwelling species consisting of red, black, yellowedge, gag, warsaw and other species of groupers, amberjacks, triggerfish, porgies, tilefish, and red, vermilion and other snapper species. The Gulf reef fish fishery extends throughout the Gulf of Mexico from Texas to the Florida Keys. The analysis in this paper will focus on the eastern region of the fishery from Panama City, Florida east and south along the Florida coast to the Florida Keys. Grouper species are the main target species in this region of the fishery.[7] Vertical hook and line and longline fishing gear are the two main gear types used.

Current management measures in the fishery include a combination of permit moratorium, total quotas which are enforced with seasonal closures, minimum size limits and trip limits. The commercial shallow water grouper total allowable catch (TAC) is set at 8.80 million pounds gutted weight. Red grouper, which is a member of the shallow water species group has a separate TAC of 5.31 million pounds (gutted weight). These quotas are enforced with seasonal closures that are enacted when either the shallow water or the red grouper TAC is met. Existing minimum size limits are set at 24 inches for black and gag grouper, 20 inches for yellowfin and red grouper, and 16 inches for scamp. The fishery is closed for one month (February 15 through March 15). An aggregate trip limit of 6,000 pounds of shallow water and deep water groupers combined was introduced for the 2006 fishing season.

The commercial deepwater grouper TAC is currently set as 1.02 million pounds. The commercial tilefish TAC is currently set at 440,000 pounds. There are no size limits for deepwater grouper species or tilefish since these fish do not survive retrieval from the depths in which they are caught. Amendment 30B to the Reef Fish Management Plan proposes a separate TAC for gag grouper. The implications of the gag quota are discussed further in Section 5.

Amendment 29 to the Reef Fish Fisheries Management Plan identifies alternative IFQ program designs. Each allocates shares of total species-specific target quotas, which are determined by the management authority. The pounds of fish that can be legally landed by a fishermen are then determined as the shares owned times the total quota. Designs differ with regard to the *coarseness* of species groups. For example, one proposed design allocates harvest shares for: (i) red grouper, (ii) gag grouper, (iii) other shallow water groupers including red hind, shallow water scamp, black, yellowmouth, and yellowfin grouper, (iv) deepwater groupers, including yellowedge grouper, warsaw grouper, snowy grouper, misty grouper, deepwater scamp, and speckled hind, and (v) tilefish. A

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[7] Weninger and Waters (2003) analyze the benefits of adopting a rights-based management program in the northern Gulf reef fish fishery using standard non-parametric (data envelopment analysis) methods.

second proposal would allocate shares for (i) all shallow water groupers, (ii) all deepwater groupers and (iii) tilefish. A third proposal would allocate shares for (i) all groupers and (ii) tilefish.

3.1 Data

The data used in this study are from the National Marine Fisheries Service log book reporting system, and a survey of annual operating expenses that was conducted by the Southeast Fisheries Science Center. Following each reef fish trip, commercial vessel operators must record the trip's harvest quantities by species, the gear type used on the trip, the primary area of fishing, the number of crew on board the vessel and other trip characteristics. In 2003, a "Trip Expense & Payment Section" was added to the logbook reporting form. The added section elicited trip revenue by species, fuel, bait, ice, and food expenditures, along with payments to the captain and crew. Mandatory expense and payment data collection began in 2005 for a stratified sample of the Gulf reef fish fleet.

In summary, data available for analysis consist of standard log book data for the Gulf commercial fleet from 2000-2006. Expense and payment data are from a stratified sample of roughly 25% of the eligible reef and mackerel permit holders for 2005-06.

3.1.1 Effort and catch data

The analysis will focus on fishing trips taken in the eastern Gulf of Mexico reef fish fishery, where the bulk of the grouper species are harvested. The region extends from the Mississippi River delta east along the Florida coast to the Florida Keys.[8] The target species in the eastern Gulf region are primarily grouper species, although a host of other reef fish species including snappers (primarily vermilion) and non-reef fish species such as mackerel, tunas, and sharks are also harvested.

Table 1 reports 2002-06 effort and landings information for the vertical line gear and the longline gear types. Total effort measures reported include the number of boats, total trips, total days at sea (DAS) and total crew days at sea, which is calculated as the number of individuals on board the vessel times the days spent at sea. The table includes the average DAS per trip, and the average pounds harvested per trip on all trips for all species. Lastly, we report the total landings of deep water groupers (DWG), shallow water groupers (SWG), snappers and other reef fish (Snp./Oth.), and non-reef fish species (N. Reef).

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[8] The Gulf reef fish fishery extends west along the Texas coast to Mexican waters. The primary target species in the western or northern Gulf region is red snapper. A red snapper individual fishing quota management program was implemnted in 2007. Analysis of the northern Gulf region is reserved for future work.

Vertical Line Gear

	Total Effort				Per Trip Ave.		Total Landings (thous. lbs.)			
Year	Bts.	Trips	DAS	Crew DAS	DAS	Lbs.	DWG	SWG	Snp./Oth.	N. Reef
2002	478	4,686	15,129	29,688	3.23	821	35.0	2,472.2	1,051.6	287.1
2003	448	4,610	14,360	27,785	3.12	684	88.1	1,841.9	974.3	249.5
2004	436	4,337	13,355	26,021	3.08	806	75.7	2,019.6	1,066.9	333.7
2005	416	3,767	11,935	23,103	3.17	840	40.8	1,865.0	999.7	259.2
2006	370	3,488	12,490	23,986	3.58	837	79.0	1,622.2	941.4	275.3

Longline Gear

	Total Effort				Per Trip Ave.		Total Landings (thous. lbs.)			
Year	Bts.	Trips	DAS	Crew DAS	DAS	Lbs.	DWG	SWG	Snp./Oth.	N. Reef
2002	141	1,343	11,090	33,782	8.26	5,024.3	482.5	4,966.9	207.6	1,090.6
2003	139	1,502	12,298	38,069	8.19	4,877.4	798.8	4,845.1	318.0	1,364.0
2004	145	1,463	11,977	37,194	8.19	5,098.0	942.8	5,219.7	355.1	940.9
2005	132	1,320	9,519	29,292	7.21	4,695.4	785.8	4,358.4	250.5	803.3
2006	119	1,439	11,101	34,201	7.74	4,282.7	689.7	3,950.3	369.2	1,153.6

Table 1: **Eastern Gulf Region Effort and Landings: 2002-06.** `DAS denotes days at sea; Lbs. are denoted in round weight; DWG is deep water groupers; SWG is shallow water groupers; Snp./Oth. is snappers and other reef fish species; N. Reef is non-reef fish species. Data are from the NMFS log book reporting system.`

The vertical line gear summary statistics indicate a decline in the number of participating boats, total trips, and crew DAS during the 2002-05 data period. This trend is not apparent in the 2006 data. The cause of the decline in the vertical line effort is difficult to determine. Declining effort is consistent with a tightening of commercial harvest regulations during the data period and/or declining reef fish stock abundance. Other factors such as increased fuel prices may also play a role.

An average vertical line trip lasts 3 to 3.5 days during which time vessels harvest an average of 800-840 total pounds of fish. It should be noted that the fleet average catch per trip masks the fact that a *highliner* vertical line boat will typically harvest 3,000-5,000 pounds on a trip. The average in the table is significantly lower because a large segment of the vertical line fleet are part time vessels that harvest small quantities of fish both at the trip level and on an annual basis.

Total landings on vertical line fishing trips are reported in the last four columns of Table 1. Shallow water groupers are the main target species for vertical line gear although snappers and other reef fish are also important. Non-reef fish species and deep water groupers make up considerably smaller shares of the total harvest for the vertical line gear fleet.

Turning to the longline gear we see a similar downward trend in the total effort measures during the 2002-05 period, with a small increase in each effort measure in 2006. A smaller number of boats employ longline gear than vertical line gear, and fewer longline trips were taken during the data period.

An average longline vessel is larger (45.4 feet) than an average vertical line boat (35.6 feet), takes longer trips (typically 7 to over 8 days at sea) and employs a larger crew. On average, longline boats carry 2.97 individuals (captain plus crew), whereas vertical line boats carry 2.12 individuals. Longer trips with a larger crew translate into a per trip harvest that is considerably larger than on a vertical line trip. It is not unusual for a highliner longline gear boat to land 8,000 to 10,000 pounds on a trip. The fleetwide harvest by longline gear vessels is larger for all species groups except the snapper and other reef fish (Snp./Oth.) category.

The summary statistics in Table 1 indicate that the species mix at the aggregate level differs across the two gear types. An investigation of trip-level harvesting activity further demonstrates these differences. Focusing on the 2006 harvest season (results for 2002-2005 are very similar, with no trends indicated during the period) finds that harvest shares on an average vertical line gear trip include 1.8% deep water groupers, 46.7% shallow water groupers, 39.1% snappers and other reef fish, and 12.4% non-reef fish species. On an average longline trip, the catch includes a larger share of deep water groupers (9.5%), shallow water groupers (62.8%) and non-reef fish (22.2%), and a smaller share of snappers and other reef fish species (5.5%).

Vertical Line Gear							
Year	Obs.	Rev.	Costs	Fuel[a]	Bait	Ice	Labor
2005	1,731	$2,974	$1,514	24.96%	9.31%	5.54%	61.19%
2006	1,560	3,192	1,825	24.77	8.86	6.00	60.37
Longline Gear							
Year	Obs.	Rev.	Var. cost	Fuel[a]	Bait	Ice	Labor
2005	475	$9,440	$5,478	18.07%	15.10%	5.23%	61.60%
2006	658	9,606	5,793	19.52	14.83	4.23	61.42

Table 2: **Per Trip Harvest, Revenue and Variable Cost.** `Source: NMFS log book reporting system.` a `- reported values are percentage shares of trip expense.`

Summarizing the fishery-wide trends, we find that total participating vessels (both gear types) fell from 592 in 2002 to 469 in 2006. Total trips fell by 18.3% from 6,029 in 2002 to 4,927 in 2006. Total days at sea fell by 10% during the same period.[9] Combined landings across the two gear types indicate that the aggregate harvest of deep water groupers, along with snappers and other species, increased. Aggregate shallow water grouper landings declined by roughly 25%, whereas the non-reef fish harvest varied with no apparent trend.

3.1.2 Trip revenue and expenses

Log book data indicate that 10,014 trips landed reef fish in the eastern Gulf region during the 2005-06 harvest seasons. Of these, 3,432 (34.3%) have complete trip expense information. Trip expense data were examined for possible reporting errors. This procedure identified 35 observations for which the reported variable costs per landed pound was an order of magnitude above the dockside price, or considerably below the reported expenses for remaining observations. There were 23 trips that reported crew sizes in excess of five, ten trips reported landings in excess of 15,000 pounds, and two trips that reported variable costs in excess of $10,000. These trips were deemed non-representative and were dropped. There are 3,362 observations available for the cost analysis. Of these, 2,229 observations are vertical line trips taken by 238 unique vessels. The remaining 1,401 observations are longline gear trips taken by 101 unique vessels.

Table 2 summarizes the number observations, average revenue and (variable) costs per trip, along with a percentage breakdown for the main trip expense categories: fuel, bait, ice and labor.

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[9] Concerns of declining stock levels for some grouper species and tighter harvesting restrictions imposed in 2005 may explain this trend, and particularly the sharp drop in effort between 2004 and 2005.

Log book data forms record crew shares (in dollars), the number of crew on board, and the days at sea for the trip. This data exhibited unreasonable variation in the wages paid to captain and crew members, per day at sea. We suspect this variation is due to inconsistencies in reporting of crew payments. Further examination indicates that in some cases a combined skipper and boat share was recorded in the *share* field when the owner of the vessel was also the skipper for the trip. In other cases, the boat share was separated from the share paid to the captain and crew. These anomalies confound the actual wages paid to captain and crew labor. Therefore, labor expenses in Table 2 are calculated as the median reported wage per day at sea (during the year the trip is taken) times the total days at sea, times the number of crew plus the skipper on board the vessel. The labor wage is assumed to represent the cost of labor if employed in its next highest value use.

Sample average revenue per trip for vertical line gear vessels is roughly $3,000 and trip variable costs are about half of revenue. Labor for the captain and crew make up the largest share of trip costs exceeding 60%. Fuel represents the next highest cost category at roughly 25% of trip expenses. Ice and bait comprise smaller shares of trip expenses.

As noted above, longline trips are typically longer, taken by larger vessels with a larger crew. Sample average per trip revenue for longline gear trips is roughly three times higher than for vertical line gear trips. Trip expenses are also higher ranging on average between 58-60% of trip revenue. The average share of labor expense on a longline trip is very similar to a vertical line trip. Fuel expenses on average comprise a smaller share of trip costs, whereas bait makes up a larger share of trip expenses for longline gear trips.

3.2 Econometric estimation

Model tractability requires that individual reef fish species be aggregated into output groups. Output groups in this study are formed based on similarity in harvesting practices, e.g., fishing locations, depths, bait, and capture methods used to harvest the different species within each group. To the extent possible, output groupings mirror the proposed IFQ program design as described in Amendment 29. Harvested quantities within each output category are aggregated linearly. The aggregation procedure assumes that optimal input choices and aggregate output levels can be chosen independently of the mix of species within each output category. The harvest technology is thus assumed to exhibit weak output separability. Linear aggregation implies a constant rate of transformation among harvested species within each output group.[10] The output categories include:

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[10] These assumptions are consistent with fishing practices as described to us by grouper fishermen. Nonetheless, it should be noted that output aggregation could bias the results that follow.

(i) deepwater groupers and tilefish[11], (ii) red grouper, (iii) gag grouper, (iv) other shallow water groupers; (v) snapper species, (vi) other reef fish, and (vii) non-reef fish (migratory pelagics, tunas, sharks, crustaceans).

To estimate the trip-level cost function in equation 1, we require a proxy for short run fixed capital k and a functional form for the non-target component $g(w, h, k|\beta)$. We wish to control for differences in short run fixed factors across vessel operations in our data. Such factors may include services provided by the vessel, engine and electronic equipment, and labor provided by the captain and crew. A commonly used proxy for capital is vessel size which is typically measured as length or total water displacement of the hull. Vessel characteristics are not recorded in the log book data base. We were able to match vessel length data obtained from the survey of annual operating expenses to 81.6% of the vertical line trips and 88.7% of longline trips. To avoid dropping further observations from the regression analysis we instead use the number of crew (including the captain) on board the vessel to proxy for the short run fixed factors. Crew size is clearly an important factor of production which is not easily adjusted at the trip level due to the fixed number of berths on board. We find further that crew size and vessel length are strongly correlated.

The functional form for the non-target component $g(w, h, k|\beta)$ is assumed quadratic in harvest and crew size (details are presented in an Appendix). The harvest vector h is entered linearly and quadratically, as is the crew size. A crew-harvest cross term, $crew \cdot h$, is added to capture the effect of larger crew size on the unit cost of harvesting reef fish. The fuel price is entered linearly (a quadratic specification was rejected).[12] A dummy variable for trips taken during the 2005 fishing season is included.

Lastly, the total number of fishing trips taken by each vessel during each year is inserted to proxy for differences in harvesting efficiency across vessels. It is reasonable to suspect that vessel operations that take more trips per year are more familiar with the location of highly productive fishing sites and/or employ more skilled crew than do part time boats. Correspondingly, the prior expectation is that trip costs are a declining function of the total annual trips taken by the vessel.

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[11] Creating a separate tilefish output category violated data confidentiality requirements. Tilefish are combined with deepwater groupers because they are harvested with similar gear, often at similar depths.

[12] The data include bait expenses only. Since bait is heterogenous and bait types are not recorded, a bait price could not be constructed. Similarly, the price for ice is not reported. These omissions are not likely to detract from the analysis as it is reasonable to assume that bait and ice use is proportional to harvest, and that input substitution possiblities are small or nill. Moreover, bait and ice are small components of trip expenses.

	DWG $i = 1$	Red Grp $i = 2$	Gag Grp $i = 3$	Oth. Grp $i = 4$	Snap $i = 5$	Oth Reef $i = 6$	N. Reef $i = 7$
$\widehat{\gamma}_i$	0.106 (0.027)	0.018 (0.003)	0.088 (0.006)	0.081 (0.008)	0.033 (0.005)	0.028 (0.006)	0.038 (0.005)
$\widehat{\varphi}_i$	0.089 (0.018)	0.130 (0.030)	0.059 (0.010)	0.075 (0.012)	0.297 (0.024)	0.284 (0.027)	0.066 (0.017)
$\overline{\theta}_i$	0.013	0.281	0.169	0.062	0.329	0.111	0.035
$\overline{p}_i$	1.950	2.228	2.752	2.718	2.319	1.024	1.315
$\overline{c}_i$	0.553	0.335	0.316	0.445	0.316	0.235	0.225
$\overline{p}_i - \overline{c}_i$	1.397	1.893	2.436	2.273	2.004	0.790	1.092

Table 3: **Target Component Results: Vertical Line Gear.** `DWG is deepwater groupers and tilefish; Red, Gag and Oth Grp denotes red, gag and other grouper species, respectively; Oth Reef is all other reef fish and N Reef is non reef fish. Standard errors in parentheses.`

4 Results

The parameters of the trip-level cost function are estimated using feasible generalized non-linear least squares (see Judge et al., 1985, Chapter 12). Separate parameters are estimated for vertical line and longline gear types. With few exceptions, the parameter estimates have the expected sign and low standard error. A detailed explanation of the econometric estimation procedure, parameter estimates and standard errors are reported in an Appendix. The results are summarized next.

4.1 Vertical line gear costs

Table 3 reports results for the targeting component of trip-level variable costs; vertical line gear is considered first. Included in the table are the sample average harvest shares, denoted $\overline{\theta}_i$, average dockside prices, $\overline{p}_i$, the sample average of the estimated marginal costs, $\overline{c}_i$, and the sample average marginal variable profit, $\overline{p}_i - \overline{c}_i$. It should be noted that trip labor costs are not included in trip expenses and thus the marginal return $p_i - c_i$ represents the incremental fuel, ice and bait expense required to harvest an additional unit (pound) of output group i fish.

Sample average catch shares for vertical line trips indicate that, by weight, red grouper and snappers comprise the largest shares of the average trip catch, at 28.1% and 32.9%, respectively. Gag grouper makes up an average of 16.9% of the trip catch and other reef fish species (denoted Oth. Reef) comprise 11.1%. Deep water groupers, other groupers, other reef fish and non-reef fish comprise smaller shares of the average trip catch.

	6 Trip Vessel			20 Trip Vessel		
	Crew Size			Crew Size		
Lbs/Trip	1	2	3	1	2	3
2,000	$0.85	$0.86	$0.85	$0.78	$0.79	$0.78
2,500	0.83	0.83	0.81	0.76	0.75	0.73
3,000	0.85	0.83	0.80	0.77	0.75	0.72
3,500	0.90	0.86	0.80	0.81	0.77	0.72
4,000	0.98	0.91	0.83	0.87	0.81	0.73

Table 4: **Ray Average Variable Costs: Vertical Line Gear**

Recall that the parameter φ_i represents the species i harvest share at which the targeting cost component attains its lowest value. Comparing the estimates of $\widehat{\varphi}_1, ..., \widehat{\varphi}_7$ to sample average harvest shares $\overline{\theta}_1, ..., \overline{\theta}_7$ illustrates targeting behavior by sample vertical line vessels. Results find that the sample average share for red grouper, gag grouper and snapper species are each above their minimum target cost counterparts, i.e., $\overline{\theta}_i > \widehat{\varphi}_i$ for $i = 2$, 3, and 5. Sample average shares for the remaining species groups fall below the minimum target cost share counterparts. These findings suggest that vertical line fishermen incur costs to target red grouper, gag grouper and snapper species, and/or incur costs to avoid deepwater groupers, other groupers, other reef fish and non-reef fish. This targeting pattern is consistent with feedback from industry and managers and, with the exception of the other grouper species, is consistent with the relative dockside prices and estimated marginal net returns. All else equal, we would expect vertical line fishermen to target higher priced species and take efforts to avoid lower priced species. Notice, for example, the sharp difference between harvest shares and minimum target share for gag grouper $\overline{\theta}_3 = 0.169$ versus $\widehat{\varphi}_3 = 0.059$. The result suggests that efforts are taken to seek out gag, which is not surprising given its relatively high dockside price. On the contrary, $\overline{\theta}_6 = 0.111$ is smaller than $\widehat{\varphi}_6 = 0.284$; the result suggests skippers take actions to avoid other reef fish species, which have the lowest average dockside price.

The estimate of the skipper residual profit parameter η is 0.132 (with estimated standard error 0.001). This result indicates that vertical line gear skippers are the residual claimant of 13.2% of trip variable profits. This finding is in line with the skipper shares reported in our data.

Parameter estimates and standard errors for the non-target component of trip costs are reported in an Appendix. We summarize the results by reporting fitted trip expenses at various harvest levels, crew sizes, and number of trips taken per year.

Table 4 reports the estimated ray average variable cost (RAVC) for vertical line gear fishing trips.[13] Reported values are obtained by evaluating fitted costs under the final parameter estimates. We then add an estimate of the labor expenses for the trip. Labor expenses are calculated as the median crew wage per day reported in the 2006 data ($112 for vertical line trips) times the predicted trip length.[14] All cost estimates assume that harvest shares are equal to the average harvest shares reported in Table 3.

RAVC estimates are reported for a range of total trip pounds and varying crew sizes. To illustrate the extent of cost inefficiency in the data we report RAVC estimates for a *part time* and an *active* vessel. The part time vessel is assumed to take 6 trips per year while the active vessel takes 20 trips per year. These trip numbers represent the range appearing in the data. Total pounds per trip considered in the table are representative for an active vertical line boat. Crew sizes ranging from 1-3 are also representative of the sample vertical line gear data.

The results in Table 4 indicate that for a fixed crew size, RAVC is U-shaped with increasing returns to scale at harvest levels between 2,000-2,500 pounds per trip, and decreasing returns at a harvest between 3,500 and 4,000 pounds per trip. The harvest at which returns to scale are exhausted increases with crew size. With a single crew member, RAVC is lowest at 2,500 pounds per trip, whereas with a crew of three, RAVC is lowest between 3,000-3,500 pounds per trip. Notice that the cost estimates are only moderately sensitive to crew size, e.g., minimum RAVC varies by $0.03 from $0.83 with a single crew member to $0.80 for a vessel with a three person crew.

Comparing results for the 6- and the 20-trip per year vessels provides an indication of measured cost efficiency in the data. The comparison also suggests the pure efficiency gains are likely under an IFQ management program, as efficient vessels acquire quota from inefficient (part time) vessel operations. Note that lowest RAVC for the 6-trip/yr vessel is in the range of $0.83-$0.85, whereas RAVC for the 20-trip/yr boat is in the range of $0.72-$0.75. The cost saving is roughly 13% of trip expenses.

4.1.1 Cost efficiency: vertical line gear

The model can be used to more formally assess the cost efficiency in the sample data. We consider the following scenario. The 2005-06 sample includes 3,291 vertical line trips taken by 286 distinct vessels. These vessels harvested over 2 million pounds of reef fish, spent roughly 7,000 days at sea

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[13] The concept of ray average costs and multiple output cost technologies are explained thoroughly in Baumol et al. (1982).

[14] Trip length varies with total harvest and crew size. Regression analysis is used to estimate this relationship. The per-crew labor expense is calculated as the predicted trip length (a polynomial function of crew size and total harvested pounds) times the median daily wage.

	Total Lbs.	Bts.	Trips	DAS	Crew DAS	RAVC	Var. Cost
2005	2.400m	35	701	4,800	9,600	\$0.65	\$1.552m
		(234)	(1,731)	(6,946)	(15,455)	(\$0.73)	(\$1.753m)
2006	2.148m	28	568	3,890	7,780	\$0.75	\$1.612m
		(196)	(1,560)	(7,133)	(15,318)	(\$0.90)	(\$1.929m)

Table 5: **Ray Average Variable Costs: Vertical Line Gear.** `Results assume a 2-member crew on vessel that takes 30 trips per year.`

and allocated over 15,000 crew days at sea in each of the data years. The empirical model can be used to calculate the expenses for fuel, labor, ice and bait, days at sea, and crew days at sea that would be required on a scale and technically efficient harvesting operation. Specifically, we calculate the trip variable costs and associated effort required to harvest the 2005-06 sample reef fish catch on a two crew member vertical line boat which lands on average 3,000 pounds per trip and takes 20 trips per year. A fleet that is comprised of these representative vessel types will be referred to as the *cost efficient fleet structure*. The cost and effort that is predicted under the cost efficient fleet structure is then compared to the actual cost and effort incurred by sample vertical line vessels. This comparison illustrates the extent of the harvesting cost inefficiency in the sample data, and importantly, provides a measure of the variable cost savings and effort reductions that are expected to emerge under an IFQ management program.

Consider the results for the 2005 harvest season that are reported in the first row of Table 5. Sample vessels harvested a total of 2.400 million pounds of reef fish in 2005. If this same quantity was harvested by the cost efficient fleet structure as defined above, the fleet would consist of 35 vessels, and 701 trips would be required to land the same quantity taken by sample vessels. Actual effort and costs incurred by vertical line sample vessels are reported in parentheses. The 2005 sample includes 234 vessels that took more than double the number of trips, at 1,731, and spent considerably more days and crew days at sea. The RAVC attained by the cost efficient fleet structure is estimated at \$0.65, compared to the sample RAVC of \$0.73 (a 12.3% increase in variable costs). Variable costs savings under the cost efficient fleet are estimated at \$201,000 in 2005.

The results reported for 2006 show a similar pattern. Observe that estimated cost savings are higher at \$317,000 despite the fact that less fish was harvested on sample vertical line trips in 2006. This finding is consistent with more stringent catch limits and additional seasonal closures during the 2006 season. Higher fuel prices in 2006 (\$2.45 per gallon versus \$2.11 in 2005) also plays a role, i.e., cost savings arise from lower fuel consumption under the cost efficient fleet with the estimated cost *difference* being proportional to the fuel price.

	DWG $i=1$	Red Grp $i=2$	Gag Grp $i=3$	Oth. Grp $i=4$	Snap $i=5$	Oth Reef $i=6$	N. Reef $i=7$
$\widehat{\gamma}_i$	0.007 (0.013)	0.005 (0.014)	0.344 (0.015)	0.239 (0.018)	0.237 (0.009)	0.497 (0.039)	0.011 (0.022)
$\widehat{\varphi}_i$	0.158 (0.956)	0.375 (0.876)	0.003 (0.022)	0.208 (0.029)	0.094 (0.018)	0.141 (0.073)	0.022 (0.497)
$\overline{\theta}_i$	0.141	0.458	0.070	0.047	0.043	0.018	0.222
$\overline{p}_i$	2.163	2.275	2.811	2.770	2.203	0.951	1.088
$\overline{c}_i$	0.366	0.263	0.109	0.582	0.276	0.362	0.061
$\overline{p}_i - \overline{c}_i$	1.796	2.012	2.702	2.188	1.926	0.589	1.027

Table 6: **Targeting Component Results: Long Line Gear.** DWG is deepwater groupers and tilefish; Red, Gag and Oth Grp denotes red, gag and other grouper species, respectively; Oth Reef is all other reef fish and N Reef is non reef fish. Standard errors are in parentheses.

4.2 Longline gear costs

Table 6 reports targeting cost component results for longline gear trips. Included in the table are sample average harvest shares, $\overline{\theta}_i$, average dockside prices, $\overline{p}_i$, sample average marginal costs, $\overline{c}_i$, and the sample average profit margin, $\overline{p}_i - \overline{c}_i$ (marginal costs are estimated values).

By weight, red grouper and non-reef fish species comprise the largest shares of longline trip catch at 45.8% and 22.2%, respectively. Deep water groupers make up 14.1%. Gag, other groupers, snappers and other reef fish comprise smaller shares of longline trip harvest.

Comparing estimates of $\widehat{\varphi}_i$ and sample average harvest shares $\overline{\theta}_i$, we see that longline fishermen follow different targeting patterns than vertical line fishermen (restrictions on fishing areas for longline gear provides one explanation). Notice that with the exception of non-reef fish species there appears to be little targeting activity indicated within the sample of longline gear trips. For the most part, sample average harvest shares fall close to the target cost minimizing values, $\widehat{\varphi}_i$ (again with the exception of non-reef fish species). An explanation for the finding of less targeting behavior—one that is congruent with industry feedback and intuition—is that targeting is more costly with longline gear than with vertical line gear. Longline gear distributes baited hooks over a much larger area than vertical line gear and thus is likely to intercept a wider range of reef fish species. Notice that estimated values of the $\widehat{\gamma}_i$ parameters, which capture the rate of cost increase as harvest shares diverge from $(\widehat{\varphi}_1, ..., \widehat{\varphi}_7)$, are generally larger for longline gear than for vertical line gear (Table 3). The implication being that trip costs rise sharply when a longline skipper attempts to adjust the harvest mix away from the mix implied by $\widehat{\varphi}$.

	6 Trip Vessel			16 Trip Vessel		
	Crew Size			Crew Size		
Lbs/Trip	2	3	4	2	3	4
4,000	\$0.71	\$0.78	\$0.86	\$0.70	\$0.77	\$0.85
6,000	0.65	0.67	0.70	0.64	0.66	0.68
8,000	0.64	0.63	0.61	0.63	0.62	0.60
10,000	0.66	0.61	0.56	0.65	0.60	0.55

Table 7: **Ray Average Variable Costs: Long Line Gear .**

The estimate of the skipper residual profit parameter is $\eta = 0.091$ with estimated standard error 0.0004. The results indicate that longline skippers are the residual claimant of 9.1% of trip variable profits. This finding is in line with the skipper shares reported in our data.

Table 7 summarizes the structure of the longline trip variable cost function. The table reports RAVC evaluated at the sample harvest mix over the range of total harvested pounds observed in the data (again by active vessels in the longline fleet). Results are reported for crew sizes ranging from two-four which is representative of longline gear trips, and compares costs for a 6- and a 16-trip per year vessel. Differences in the assumed number of trips per year illustrate the cost efficiency across relatively inactive and active vessels.

For a crew size of two, we see that RAVC is U-shaped with a minimum occurring at 8,000 pounds per trip. For crew sizes of three and four, RAVC falls over the range of total harvested pounds reported in the table. This result suggests that longline gear vessels operate in a region of increasing returns to scale (at the trip level) over the range of harvest levels typical in our data. The implication is that average costs per landed pound would fall if trip harvest increased. This finding is explained by the 6,000 pound per-trip catch limit regulations for grouper species that was imposed during 2005-06. Examination of historical logbook data provides further evidence that recent regulations have impacted longline harvesting activity. From Table 1 in Section 3 we see that average days at sea on longline trips and average pounds per trip fell by 11.9% and 7.9%, respectively, in 2005, the year that per-trip catch limits were introduced.[15] This evidence, while not conclusive, suggests that regulations may be responsible for the longline gear scale inefficiency indicated in the sample data. Lastly, notice that the cost differences across active and inactive vessels amounts to roughly \$0.01 per pound, which suggests small levels of cost inefficiency in the

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[15] Results in Table 1 suggest that per-trip catch limits did not have the same effect on vertical line gear trips. It is likely that the 6,000 pound per trip limit did not bind for vertical line gear trips.

	Total Lbs.	Bts.	Trips	DAS	Crew DAS	RAVC	Var. cost
2005	2.773m	23	367	3,491	10,472	$0.58	$1.621m
		(78)	(592)	(4,231)	(13,219)	($0.66)	($1.825m)
2006	3.660m	29	458	4,358	13,075	$0.60	$2.211m
		(74)	(809)	(6,332)	(19,204)	($0.72)	($2.642m)

Table 8: **Ray Average Variable Costs: Long Line Gear .**

longline data.

4.2.1 Cost efficiency: longline gear

Cost efficiency for longline sample vessels is analyzed following the same approach used for vertical line trips. The 2005-06 sample includes 1,401 longline trips taken by 101 different vessels. Data indicate that 2.773 million pounds were harvested in 2005 and that 3.660 millions pounds were harvested in 2006. The total effort allocated on sample longline trips is reported in parentheses in Table 7.

The fitted empirical model is used to predict expenses for fuel, labor, ice and bait, days at sea, and crew days at sea that would be required if the 2005-06 longline sample catch was harvested by scale and technically efficient harvesting operations. We calculate trip costs and associated effort incurred on a three-crew longline vessel that harvests an average of 8,000 pounds per trip and takes 16 trips per year. As above, this exercise measures the extent of the harvesting inefficiency in the sample data and the variable cost savings and effort reductions that are available under a cost efficient fleet structure. Because this fleet structure is expected to emerge under the proposed IFQ management program, the results provide an indication of the benefits (cost savings) that will arise under new management.

Consider the 2005 results in Table 8. Sample vessels harvested 2.773 million pounds of reef fish in 2005. If this same catch were harvested by the cost efficient fleet structure, the fleet would consist of 23 boats and 367 trips would be required. Actual effort and costs for sample longline vessels (in parentheses) indicate that 78 vessels participated in 2005 and that 592 trips were required. Sample vessels spent more days at sea and more crew days at sea than would be required under the cost efficient fleet.

RAVC attained by the cost efficient fleet structure is estimated at $0.58 in 2005. In comparison, the sample RAVC is estimated at $0.66. Results indicate that a variable costs savings of $204,000 would be obtained under the cost efficient fleet structure in 2005.

The results reported for 2006 are similar. Under the cost efficient fleet structure, fewer vessels and less effort would be required to harvest the 2006 sample catch; the results suggest total variable cost would fall by $431,000 in 2006.

A final observation is that harvesting economies of scale generate the bulk of the cost savings that are predicted under the efficient longline fleet structure. Earlier results indicate that cost efficiency gains for longline gear are small at $0.01 per pound. This finding differs from the vertical line gear results where cost efficiency gains are more important.

4.2.2 Expenses for maintenance, gear, mooring and utilities

To this point the analysis has focused on trip-level expenses only. We next consider annual operating expenses for reef fish vessels.[16]

A National Marine Fisheries Service survey gathered annual operating expense data. Gulf reef fish fishermen were asked to report vessel repair and maintenance expenses, purchases of new gear and capital, and dockage rental and utility expenses. In addition to expenditure information, vessel owners were asked to report the number of days that the vessel was used during the year for both fishing and chartering activities, and for non-fishing activities. There are 126 observations available for 2005-06.

Annual repair and maintenance expenses, gear and capital replacement costs, and dockage and utility expenses are summed and are hereafter referred to as vessel maintenance costs (VMC). Investigation reveals that reported VMC's vary with the size of the vessel, measured by vessel length in feet, and the total days at sea (all uses). The following model of VMC is estimated with ordinary least squares regression:[17]

$$\begin{array}{lccccc} \ln \text{VMC}= & -5.761 & + & 1.647 \cdot \ln len & + & 0.443 \cdot \ln DAS \\ & (1.367) & & (0.433) & & (0.098) \end{array} \tag{3}$$

The results in equation 3 predict that VMC for a typical vertical line gear vessel, at 35 feet in length and 110 days at sea is $8,810 per year. A 45 foot vessel, which is the typical length for a longline gear boat, that spends 130 days at sea per year is expected to incur annual operating expenses of $14,360. To gain perspective on the magnitude of these expenses, we calculate the added costs per pound for the cost efficient fleet as defined above. A representative vertical line gear boat

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[16] The focus on variable expences facilitates comparison of costs and effort incurred by sample vessels and by the cost efficient fleet structure. Note that *part time* reef fish vessels incur annual maintanence, docking and utility expenses. What is not clear is which portion of these annual operating expenses should be allocated to reef fish fishing.

[17] The log-log specification fit the data best. The R-squared statistic for the model is 0.370. Alternative specifications and additional regressors (e.g., gear type, crew size, 2005 dummy variable) were considered and rejected.

harvests 60,000 pounds of reef fish annually (3,000 per trip and 20 trips a year). Estimated VMC thus adds \$0.147 per harvested pound. Longline vessels in the cost efficient fleet land 8,000 pounds per trip and take 16 trips per year, which implies annual harvest of 128,000 pounds. Calculations reveal that VMC expenses add \$0.112 per pound of reef fish. Combining these costs with the RAVC estimates reported in tables 4 and 7 suggests a cost advantage for the longline gear type. This cost advantage is explored further below.

A final cost incurred by reef fish fishermen is the purchase price of the fishing vessel. Commercial fishing boats represent a significant capital investment and are *specific* in the sense that they have few alternative uses in the economy and discretely lower values when employed in these alternative uses. An initial investment in a fishing boat must be recouped over its productive life. The specific nature of the investment and the uncertainty faced by fishermen (both production and regulatory uncertainty) suggest a relatively high required rate of return is appropriate to calculate an annual rental price for a fishing vessel. Unfortunately, our data do not contain vessel value information. Consequently, net profit calculations reported below will be interpreted as returns to all fixed factors, which in the case of a fishery, include the sum of rent to the fish stock and the rent to vessel capital employed in the fishery.

5 Fleet structure, costs and rent under IFQs

Results reported in the previous section indicate that economies of scale and cost (pure technical) efficiency gains are unexploited under the current controlled access management program in the Gulf grouper fishery. Incentive to exploit these economies under IFQ management suggests that the reef fish harvest will be consolidated onto fewer, cost efficient vessels, and that some boat will exit the fishery. An examination of the pattern of vessel exit en route to the IFQ-regime fleet structure equilibrium is beyond the scope of this paper. Rather, we focus on characterizing the equilibrium fleet structure, total fleet effort and harvesting cost predicted in equilibrium under IFQ management.

With IFQs, vessel operations will no longer be constrained by catch limits and seasonal closures. Catch per vessel during a fishing season will be constrained instead by the quantity of harvest permits held, by weather conditions, or possibly mechanical failure. To characterize the fleet structure that will emerge under the IFQ system, we require an estimate of the annual harvest that could be achieved by representative vessels. This estimate is determined as the cost efficient catch per trip identified above, times the trips taken per year. Our approach is to examine past data on days spent at sea by vessels operating in the reef fish fishery. We then calculate annual trips and annual harvest per boat.

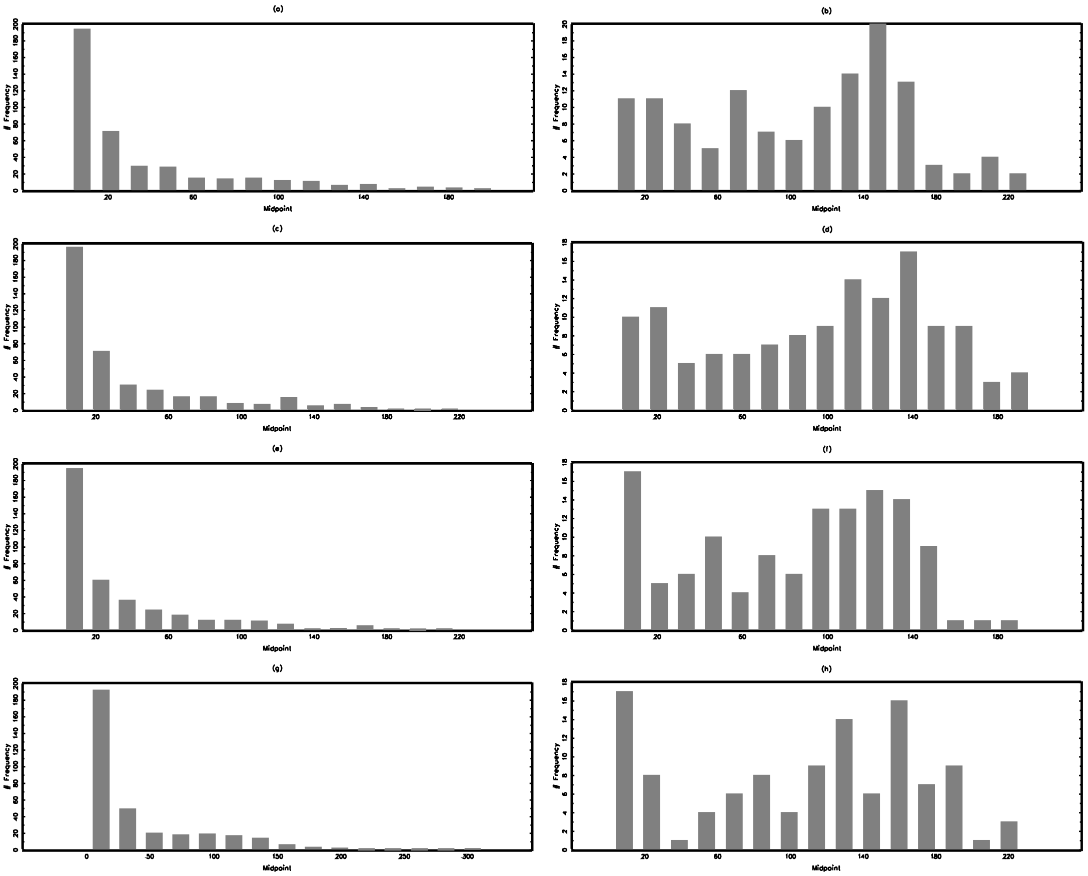

Figure 1: Annual Days at Sea in the Eastern Gulf Reef Fish Fishery (2003-06). Left hand panels report days at sea for vertical line gear boats from 2003 (top panel) through 2006 (bottom panel). Right hand panels report days at sea for longline gear boats from 2003 (top panel) through 2006 (bottom panel).

Figure 1 plots annual days at sea for vertical line and longline gear vessels that took a significant component of their annual days at sea (at least 25%) in the eastern Gulf reef fish fishery. The data are reported for 2003 in the top panels of the figure, through 2006 in the bottom panels of the figure. Left hand panels plot days at sea for primarily vertical line gear vessels (75% of DAS used vertical line gear). Right hand panels plot days for longline gear vessels (75% of DAS used longline gear).

Results for vertical line gear boats (left hand panels) indicate that over 45% of participating vessels fished less than 20 days per year during 2003-06. As noted previously, the vertical line fleet includes a significant number of part time vessel operations. These boats take a small number of

Mixed Fleet

Gear	DWG	SWG	Snp./Oth.	Bts.	Trips	DAS	RAC	Rev.	Cost	Rent
Vert.	0.150m	2.957m	3.685m	148	2,590	17,728	$0.94	$17.636m	$2.990m	$14.646m
Long.	1.310m	5.843m	1.990m	85	1,332	12,676	$0.75	$23.809	$3.603	$20.206
Total	1.460m	8.800m	5.675m	233	3,922	30,404	$0.83	$41.445	$6.593	$34.852

All Longline Fleet

Gear	DWG	SWG	Snp./Oth.	Bts.	Trips	DAS	RAC	Rev.	Cost	Rent
Long.	1.460m	8.800m	5.675m	146	2,304	21,915	$0.71	$41.193m	$4.401m	$36.793m

Table 9: **IFQ Fleet Structure, Effort and Rent.** SWG combines red, gag and other shallow water grouper species. Snp./Oth. combines snappers, other reef fish and non-reef fish species. Total allowable catch levels are in millions of pounds, gutted weight. Mixed fleet results allocate 52.5% of total pounds to vertical line gear, and 47.5% to longline gear.

trips and harvest small quantities of reef fish each year. Active vertical line gear boats, on the other hand, regularly fish for over 100 days per year and some boats spend over 150 or more days at sea per year fishing for reef fish.

Results for longline gear boats indicate a larger proportion of the fleet are *active vessels* that fish for considerably more days annually. As indicated in the figure, it is not uncommon for longline gear boats to spend 150-200 days at sea annually. The data indicate the presence of part time operations, although the number of vessels in this category is much smaller than for vertical line boats.

Results in Figure 1 are suggestive of the time that vessels will fish under IFQs.[18] It is assumed that vertical line gear boats will fish for 120 days annually, and longline gear vessels will fish 150 days per year under an IFQ management program. These assumptions are used below to determine the annual number of trips and, correspondingly, the total pounds harvested per vessel each year.[19]

Table 9 reports estimates of fleet size, effort, revenue, cost and the rent to fixed factors that are predicted under the IFQ equilibrium as described in Section 2. Total grouper quotas are assumed to follow current TAC levels. A scenario considering a reduced gag and increased red grouper

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[18] Days at sea data reported in Figure 1 may have been influenced by seasonal closures that have been imposed for grouper and tilefish since 2004 (Smith, et al., forthcoming).

[19] Annual operating costs for a vessel operation (Section 2) relate to trip-costs as follows: $C(\tau h,,w,k,x) = \tau c(h,w,k,x) + VMC$, where $c(h,w,k,x)$ includes per trip labor expenses.

quota is examined below. The DWG quota (which includes tilefish) is set to 1.460 million pounds gutted weight (1.02 million pounds for deep water grouper and 440,000 pounds for tilefish); the SWG quota, which includes red, gag and other shallow water grouper species, is set at 8.800 million pounds. The SWG quota is divided into a red grouper quota of 5.31 million pounds, a gag grouper quota of 2.810 million pounds, and an other grouper species quota of 680,000 pounds.

It is clear that reef fish fishermen operating under an IFQ management program will continue to intercept and land snapper species, other reef fish species and non-reef fish species. The proposed grouper IFQ program design includes tradable harvest permits for grouper and tilefish species only. To approximate the IFQ-regime conditions, Table 9 assumes that the fleetwide harvest of Snp./Oth. species will equal the total catch for these species reported in the 2006 log book data on trips that landed groupers. It should be emphasized that this assumption does not imply that the actual harvest of these species will remain unchanged if managed outside the umbrella of the grouper IFQ program (see Weninger 2004 for further discussion).

The results in the table assume representative vertical line vessels which are 35 feet in length and carry a crew of two. Vertical line boats are assumed to harvest 3,000 pounds per trip and take roughly 18 trips per year on average. The annual number of trips is obtained as the assumed total days at sea, 120 for vertical line gear, divided by estimated trip length.

Representative longline vessels are assumed to be 45 feet in length, with a crew of three. These boats are assumed to harvest 8,000 pounds per trip and take 16 trips per year, where trips per year are calculated similarly, as annual days at sea (150) divided by the estimated trip length. The crew wage is set at \$112 per day for vertical line gear boats and \$141 per day for longline gear boats, which are the 2006 median wages from our sample data. Fuel and dockside prices are set at the 2006 sample averages for the respective gear types.

The results in the top half of the table consider a mixed fleet made up of both vertical line and longline gear types. For this scenario, total quotas are allocated to the two gear types in the same proportions that are indicated in the 2006 logbook data.

The results indicate that the equilibrium mixed fleet will include 233 vessels, 148 vertical line boats and 85 longline boats. Total trips are estimated to be 3,922. Vertical line boats allocate more days at sea even though they harvest a smaller share of the fleet-wide catch.[20] Vertical line gear attains RAC of \$0.94, whereas longline gear attains RAC of \$0.77 per pound. The weighted average RAC for the mixed fleet is \$0.83. Total fleet revenues are \$41.445 million. Total fleet costs are predicted to be \$6.593 million, which implies an annual rent to vessel capital and the reef fish

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[20] Total crew days at sea are easily calculated as two times the total days at sea for vertical line boats and three times total days at sea for longline boats.

resource of \$34.852 million.

These numbers suggest that considerable rent is available in the reef fish fishery under a streamlined fleet that exploits available economies of scale and cost (pure technical) efficiency. The model predicts the streamlined IFQ fleet could attain RAC in the range of \$0.83 per landed pound. Average dockside prices for groupers are in the range of \$1.95 for deepwater groupers (vertical line gear) to \$2.81 for gag groupers (longline gear). This suggests per-pound rent to fixed factors in the range of \$1.12 to \$1.98 per pound. The grouper quota exceeds 12 million pounds (round weight) which implies rent for grouper species alone in the range of \$13.44 million to \$23.76 million annually. Adding to this the rent from snappers, other reef fish and non-reef fish species pushes the total rent estimate to almost \$35 million annually.

The analysis in Section 4 indicated a cost advantage for longline gear. Vertical line vessels that cannot match the costs attained on longline boats will find quota ownership costly and will face incentives to either switch gear types or exit the fishery. The model predicts that harvesting permits will gravitate to the hands of longline gear vessel operators. Results in the bottom half of Table 9 assume a fleet comprised exclusively of longline boats. Under a longline only fleet, 146 boats will be active and 2,304 trips will be required to harvest the reef fish quota. Fleet-wide RAC is predicted to fall to \$0.71 per pound.[21] Revenues (which are evaluated at the average dockside prices for respective vessel types) are \$41.193 million. Costs under the exclusively longline vessel fleet are lower than under the mixed fleet by roughly \$2 million, and the model predicts annual rent to fixed factors at \$36.793 million.

Further calculations provide an estimate of the cost *savings* that are expected under the IFQ management program. Due to difficulties in accounting for maintenance cost savings, only *variable* cost savings are reported.

Analysis of the sample data indicates that the actual RAVC incurred under controlled access management is \$0.90 per pound for vertical line gear and \$0.72 per pound for longline gear. Results suggest that costs will fall under IFQs to \$0.75 and to \$0.62 per pound, respectively, for the two gear types. Extrapolating these savings to the total round weight quotas from Table 9 indicates variable cost savings in the range of \$2.226 million per year under the mixed fleet structure scenario, and \$3.236 million per year under the longline only fleet scenario. From the predicted fleet sizes reported in Table 9, it is clear that variable costs savings alone will underestimate the total cost savings expected under the proposed IFQ management program. Maintenance cost savings could be substantial as the active reef fish fleet downsizes from current levels to those reported in the

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[21] Recall that harvesting costs are a function of total pounds harvested, as well as the mix of individual species. The model suggests that longline RAC is lower at the species mix implied under the longline only fleet scenario.

Mixed Fleet

Gear	DWG	SWG	Snp./Oth.	Bts.	Trips	DAS	RAC	Rev.	Cost	Rent
Vert.	0.150m	2.257m	3.685m	77	2,314	15,843	$0.82	$15.298m	$2.387m	$12.912m
Long.	1.310m	5.393m	1.990m	132	1,266	12,044	$0.77	$22.105m	$3.618m	$18.487m
Total	1.460m	7.650m	5.675m	209	3,580	27,887	$0.79	$37.403m	$6.005m	$31.399m

All Longline Fleet

Gear	DWG	SWG	Snp./Oth.	Bts.	Trips	DAS	RAC	Rev.	Cost	Rent
Long.	1.460m	7.650m	5.675m	135	2,134	20,301	$0.74	$37.101m	$4.331m	$32.770m

Table 10: **IFQ Fleet Structure, Effort and Rent.** SWG includes red, gag and other shallow water grouper species. Snp./Oth. includes snappers, other reef fish and non-reef fish species. Total allowable catch levels are in millions of pounds, gutted weight. Mixed fleet results allocate 41.2% of TAC's to vertical line gear and 58.8% to longline gear.

table. Logbook data indicate that 489 vessels reported reef fish landings in the eastern Gulf region of the reef fish fishery in 2006 (Table 1 in Section 3). As noted, many of these vessels are part time operations. Nonetheless, the extent of the fleet downsizing that is predicted by the model is substantial.

A final consideration is the expected trading price for tradable harvest permits under the IFQ management program. Current dockside prices for the various reef fish species and RAC estimates reported in Table 9 indicate roughly the per-pound profits that are available under IFQ management. For the mixed fleet scenario RAC is estimated at $0.83. This suggests per pound profits in the range of $1.23 for deep water groupers and tilefish, to $1.95 per pound for gag grouper. Recall that the above cost estimates do not include a rental price for vessel capital. Bargaining arrangements between permit owners and fishermen will also be an important determinant of actual permit lease prices. With these caveats in mind, the model suggests that grouper permit lease prices in excess of $1.00 per pound could be observed under IFQ management. The perpetual ownership price for quota will be impacted by numerous factors (see Newel et al., 2005 for additional discussion).

Table 10 reports results under alternative assumptions for total harvest quotas in the fishery. In this second scenario the annual quotas for deepwater groupers and tilefish, and the assumed harvest of snappers, other reef fish and non-reef fish are unchanged from above. The SWG quota is reduced from 8.800 million to 7.650 million pounds, gutted weight. This adjustment embeds an increase in the red grouper quota from 5.310 million to 6.785 million pounds, and a reduction in the gag quota from 2.810 million to 1.220 million pounds. The adjustments to the annual red and gag grouper quotas are currently being considered by regulators (Amendment 30, Gulf of Mexico Fishery Management Council).

The results in the table are as expected: the reduced shallow water grouper quota results in smaller equilibrium fleet sizes, less effort, lower revenue and lower total costs. Note that the reduction in fleet cost is not as pronounced as the reduction in fleet size and fishing effort. For the mixed gear fleet scenario, vessels and trips are predicted to decline by roughly 10.3%. Total cost is predicted to fall by 8.9%. The explanation for this result is the added targeting costs required by longline gear vessels to harvest the mix of SWG species under the adjusted quota scenario. In particular, a sharp reduction in the gag quota combined with an increase in the red grouper quota will move the regulated harvest mix further from the cost-minimizing mix. As indicated in the table this *unbalanced* quota raises RAC for longline gear.

This result has important policy implications. First, a total quota mix that is more in line with current stock levels may save targeting costs for the fleet, and may represent a preferred alternative for managers. Second, the model indicates that adjustments in total quotas have differential impacts on gear types. Notice that RAC for vertical line boats is predicted to decline under the adjusted SWG quotas. This result highlights the fact that harvesting costs which include targeting costs, differ across the two gear types and that adjustments to the mix of harvested species affects costs and profitability differently. The model shows that RAC, fleet structure and ultimately total rent generated under the IFQ management program is impacted by the *mix* of total harvest targets chosen by the fishery manager. Singh and Weninger (2007) present a general analysis and discussion of optimal harvest policies in IFQ-managed multiple species fisheries.

6 Conclusion

This paper estimates multiple-species trip-level harvesting costs for vertical line and longline gear in the eastern Gulf of Mexico commercial reef fish fishery. The cost function that is estimated provides a comprehensive and intuitive characterization of harvesting activities in the fishery. The empirical model is used to predict the fleet structure, fishery-wide effort levels, per vessel harvest activity, revenues and total fleet harvest costs that are expected under a proposed IFQ management program for groupers and tilefish. The results suggest that significant fleet downsizing will occur and considerable harvest cost savings will emerge under the proposed IFQ program. Cost savings are due to pure cost efficiency gains as the tradable harvest permits gravitate toward the most efficient vessels in the fleet and to economies of scale. Remaining vessels are expected to fully utilize their vessel capital, i.e., take more trips per year and harvest more fish per boat, than under the current controlled access management program. The predicted fleet downsizing will lead to additional fixed cost savings (e.g., maintenance and docking fees). Lastly, the model predicts that the share of the total reef fish catch that is currently harvested by longline gear vessels will increase.

Variable harvesting cost savings due to management reform are predicted in the range of \$2.226 million to \$3.236 million annually. The additional maintenance cost savings are difficult to quantify, but are expected to be significant. Overall, the results suggest that IFQs will generate significant economic benefits relative to the current controlled access management program in the eastern Gulf grouper fishery.

7 Appendix

This appendix describes the econometric procedure used to estimate the parameters of the trip level cost function in (1).

We first introduce some simplifying notation. Denote the cost for the t'th fishing trip as

$$\begin{aligned} c(\theta_t, Z_t) &= \left[1 + \frac{1}{2}\gamma_i \left(\theta_t - \varphi\right)^2\right] \exp\left[\beta Z_t\right], \\ &= [A_t] \exp[B_t] \end{aligned} \tag{A1}$$

where θ_t is the harvest share vector and Z_t is a vector of trip-level conditioning variables:

$$Z_t = [1, h_{1t ...} h_{7t}, h_{1t}^2 ... h_{7t}^2, (crew_t \cdot h_{1t}) ... (crew_t \cdot h_{7t}), crew, crew^2, trips, d_{05}]$$

In the above, $crew_t$ denotes crew size including the skipper, *trips* is the total trips taken by the vessel during the fishing season (proxy for pure technical efficiency), d_{05} is a dummy variable that is equal to 1 if the trip was taken during the 2005 fishing season and zero otherwise.

Log transforming equation A1 and adding an error term $\epsilon_{t,0}$ obtains

$$\ln c(\theta_t, Z_t) = \ln[A_t)] + B_t + \epsilon_{t,0}. \tag{A2}$$

Necessary conditions for profit maximizing targeting behavior can be written as

$$\eta p_{t,i} = A_{t,i} \exp[B_t] + A_t B_{t,i} \exp[B_t] + \epsilon_{t,i}, \qquad i = 1, ..., m, \tag{A3}$$

where $A_{t,i}$ and $B_{t,i}$ denote partial derivatives of A_t and B_t from equation A1 with respect to the harvest of the i'th output, and $\epsilon_{t,i}, .., \epsilon_{t,m}$ are iid random errors. Let $\epsilon_0 = (\epsilon_{0,1}, ..., \epsilon_{0,T})'$ denote the $T \times 1$ error vector for the T observations in equation A2. Similarly, let $\epsilon_i = (\epsilon_{i,1}, ..., \epsilon_{i,T})'$ $i = 1, ..., M$ denote the $T \times 1$ error vector for the i'th first order condition. Finally, let $\Gamma = (\gamma, \varphi, \beta)$ denote the unknown parameters of the model.

Γ is estimated with nonlinear weighted least squares. The function to be minimized is

$$\epsilon'(\Sigma^{-1} \otimes I_T)\epsilon, \tag{A4}$$

where, $\epsilon = (\epsilon_0', ..., \epsilon_m)'$ is the $TM \times 1$ vector of random errors, obtained by stacking error vectors.

A two step procedure is used to estimate Γ. In the first step, Σ is set equal to an $m + 1$ identity matrix. Denote this matrix as $\Sigma^{(1)}$. An initial estimate of Γ is obtained by minimizing A4 conditional on $\Sigma^{(1)}$. Denote this first step estimate as $\widehat{\Gamma}^{(1)}$. Using $\widehat{\Gamma}^{(1)}$, we calculate $\widehat{\epsilon} = (\widehat{\epsilon}_0, ..., \widehat{\epsilon}_m)$ from equations A2 and A3, and estimate the variance-covariance matrix $\widehat{\Sigma} = \widehat{\epsilon}'\widehat{\epsilon}/T$. A final estimate of $\widehat{\Gamma}$ is obtained by minimizing equation A4 conditional on $\widehat{\Sigma}$.

Variable	Estimate	St. Error	Variable	Estimate	St. Error
$Const.$	-2.086	0.032	h_7^2	-0.038	0.002
h_1	0.905	0.013	$h_1 \cdot crew$	-0.078	0.004
h_2	1.090	0.010	$h_2 \cdot crew$	-0.186	0.003
h_3	0.709	0.007	$h_3 \cdot crew$	-0.055	0.002
h_4	0.834	0.009	$h_4 \cdot crew$	-0.082	0.002
h_5	0.711	0.006	$h_5 \cdot crew$	-0.016	0.002
h_6	0.554	0.006	$h_6 \cdot crew$	-0.061	0.002
h_7	0.127	0.005	$h_7 \cdot crew$	0.067	0.000
h_1^2	-0.123	0.001	$crew$	0.303	0.015
h_2^2	-0.093	0.001	$crew^2$	-0.017	0.003
h_3^2	-0.065	0.001	P_{fuel}	0.175	0.008
h_4^2	-0.117	0.003	$trips$	-0.011	0.0003
h_5^2	-0.078	0.001	D_{2005}	-0.117	0.006
h_6^2	-0.032	0.001			

Table 11: **Vertical Line Gear Parameter Estimates: Non-Targeting Cost Component.**

Variable	Estimate	St. Error	Variable	Estimate	St. Error
$Const.$	-1.690	0.028	h_7^2	-0.005	0.0004
h_1	0.318	0.003	$h_1 \cdot crew$	-0.026	0.001
h_2	0.328	0.004	$h_2 \cdot crew$	-0.019	0.001
h_3	0.227	0.005	$h_3 \cdot crew$	-0.058	0.001
h_4	0.529	0.007	$h_4 \cdot crew$	-0.065	0.002
h_5	0.292	0.003	$h_5 \cdot crew$	-0.045	0.001
h_6	0.777	0.007	$h_6 \cdot crew$	-0.182	0.002
h_7	0.167	0.004	$h_7 \cdot crew$	0.039	0.001
h_1^2	-0.013	0.0002	$crew$	0.324	0.014
h_2^2	-0.020	0.0002	$crew^2$	-0.003	0.002
h_3^2	0.001	0.0004	P_{fuel}	0.318	0.005
h_4^2	-0.055	0.001	$trips$	-0.003	0.0003
h_5^2	-0.028	0.0003	D_{2005}	0.048	0.004
h_6^2	-0.036	0.001			

Table 12: **Long Line Gear Parameter Estimates: Non-Targeting Cost Component.**

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