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Individual fishing quotas and fishing capacity in the US Gulf of Mexico red snapper fishery*

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Overcapacity (OC) and excess capacity (EC) are serious obstacles affecting the sound management of commercial fisheries around the world. The use of individual fishing quotas (IFQs) has been proposed as a promising management tool to cope with these challenges. However, the empirical evidence on the efficacy of this instrument is scarce. Drawing on a stochastic distance frontier analysis, we investigate the impact of the US Gulf of Mexico red snapper IFQ program on fishing capacity, capacity utilisation (CU) and OC. The paper also offers an alternative approach to compute species-specific capacity measurements for multispecies fisheries. Our findings show that following the introduction of the IFQ program, fishing capacity decreased, primarily due to the exit of a large number of fishing vessels. CU increased marginally indicating modest decreases in EC. Conversely, we find that OC remains high. Our estimates suggest that about one-fifth of the actual fleet could harvest the entire quota.

Key words: fisheries, productivity analysis, quotas.

1. Introduction

Developing policies that promote the sustainable use of marine ecosystems and ensure the economic viability of fishing communities is central to improving governance of fish resources around the world. In many countries, the absence of rights-based management regimes has given rise to excessive investments in capital and labour, which have placed growing pressure on fish stocks. Fishery managers grappling with this problem have customarily imposed quotas, which fostered incentives to outcompete other fishers for a share of the permissible catch, leading to rent dissipation and overcapacity (OC) (Squires *et al*. 1998; Asche *et al*. 2009; Morrison Paul *et al*. 2010).

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A well-known example of the challenges of managing fishery resources is the US Gulf of Mexico (GOM) red snapper fishery. Strict and ever-tightening regulations were not only unsuccessful in protecting and rebuilding this overexploited stock, but also encouraged unnecessary capital investments and derby fishing conditions that resulted in market gluts, depressed prices, higher harvesting costs and unsafe fishing conditions (Waters 2001). In 2007, the GOM Fishery Management Council (Council) implemented the red snapper individual fishing quota (IFQ) program to reduce OC and to eliminate, to the extent possible, the problems associated with derby fishing in the commercial red snapper fishery.

While there are multiple management tools available to control the exploitation of fish stocks; including license limitations, vessel restrictions, closed seasons and areas, and catch limits, few provide incentives that promote improved biological stewardship and economic efficiency like IFQs. Nonetheless, it is important to note that many communities and communities in partnership with governments have devised effective customary rules to regulate diverse interests and ensure the sustainability of common property resources (Ostrom 1990; Ostrom *et al.* 1999; Acheson 2006) and that academic and policy circles continue to vigorously debate the merits of IFQ programs. For instance, Grafton *et al.* (2000) argue that the assignment of harvesting privileges provides fishers the flexibility to adjust the scale and scope of their operations to increase profits rather than to maximise landings. In addition, IFQs are believed to lessen the incentives to ‘race to fish’, which decrease the spoilage and mishandling of fish, which are common problems in fisheries with tight quotas and short fishing seasons (Casey *et al.* 1995). Asche *et al.* (2009) add that IFQs provide fishers with the necessary tools to improve their technical (or harvesting) efficiency (TE) by allowing them to select and use the optimal combination of production factors. Moreover, Dupont *et al.* (2002) claim that the ability to trade quotas should facilitate the shedding of excess harvesting capacity because the most efficient operators are to buyout the less efficient operators. On the other hand, IFQs have been criticised for prioritising economic efficiency over community needs and interests. For example, Olson (2011) documents that with increased consolidation of the harvesting and processing sectors, employment tends to decrease, threatening the viability of fishing dependent communities. In addition, IFQs have also been reported to limit opportunities for new entrants because of increased capital requirements (i.e. vessels and quota shares). Despite this rich literature on the performance of IFQs, few empirical studies have quantified the effect of IFQs on the capacity of commercial fishing fleets (Nøstbakken *et al.* 2011). Table 1 presents a summary of recent studies assessing capacity in commercial fisheries. Only two of these thirteen papers assess the impact of IFQs on fishing capacity.

The objective of this study is to investigate the impact of the US GOM red snapper IFQ program on fishing capacity, capacity utilisation (CU) and OC. To tackle these questions, we employ a stochastic distance frontier

Table 1 Overview of recent empirical studies measuring capacity in fishing

Author(s) (year of publication)	Fishery	Methodology	Capacity measures	Quota	Period of analysis	Observation	Number of vessels
Castilla-Espino *et al.* (2005)	Red seabream	DEA	C, TE, CU, OC	No	1998–2001	Monthly	80
Castilla-Espino *et al.* (in press)	Anchovy	DEA	C, TE, CU, OC	No	2005–2009	Annual	37
Dupont *et al.* (2002)	Salmon	DEA, MO	C, CU, OC	Yes	1988, 1990, 1991	Annual	189
Felthoven (2002)	Pollock	SPF, MO	C, TE, CU	No	1994–2000	Annual	30
Felthoven and Morrison Paul (2004)	Pollock	ETF, MO	C, CU	No	1994–2001	Seasonal	20
Felthoven *et al.* (2009)	Flatfish	SPF, MO, LC	C, CU, TE	No	1994–2004	Weekly	45
van Hoof *et al.* (2005)	Flatfish	DEA	C, CU	No	1992–1999	Annual	60
Kirkley *et al.* (2001)	Sea scallop	DEA	C, CU	No	1987–1990	Trip	10
Kirkley *et al.* (2002)	Sea scallop	DEA, SPF	C ratios	No	1987–1990	Trip	10
Lindebo *et al.* (2007)	Mixed species	DEA, MO	CU	No	1999	Annual	97
Reid *et al.* (2005)	Tuna	DEA	C, TE, CU	No	1998–2002	Annual	50
Squires *et al.* (2010)	Halibut	DEA	C, CU	Yes	1988, 1991, 1994	Annual	107
Vestergaard *et al.* (2002)	Mixed species	DEA, MO	C, CU, OC, TE	No	2000	Annual	69

C, capacity; CU, capacity utilisation; DEA, data envelopment analysis; ETF, econometric transformation function; LC, latent class model; MO, multioutput approach; OC, overcapacity; SPF, stochastic production frontier; TE, technical efficiency.

(SDF) framework. Recent studies have advocated the use of this methodology for the following reasons: (i) it allows for the specification of multiple outputs and inputs, which is essential for studying multispecies fisheries, like the GOM red snapper fishery; and (ii) it can deal with the randomness of the fishing process since SDF does not presume that deviations from the frontier are solely caused by inefficiency but also from stochastic events such as bad weather or luck. Additionally, the parametric nature of the SDF method provides detailed knowledge about the relationship between outputs and factors of production (Orea *et al.* 2005; Felthoven *et al.* 2009).[1]

This article also contributes to the literature by proposing an alternative strategy to compute species-specific capacity measures for multispecies fisheries. In contrast to the standard approach that uses the observed catch composition proportions (contemporaneous weights), we use temporally averaged catch composition proportions (historical weights). We argue that this accommodation is necessary because the use of contemporaneous weights has yielded capacity estimates that range widely from fishing season to fishing season. These wide fluctuations are likely driven by external factors, such as market and economic conditions. In other words, the use of historical weights improves the usefulness of the estimates because it ameliorates the impact of confounding external factors not related to the actual fishing capacity of the fleet.

2. The US GOM red snapper fishery

Red snapper (*Lutjanus campechanus*) is an important reef-fish species that supports valuable commercial and recreational fisheries in the US GOM. Vertical lines and, to a lesser extent, bottom longlines are the main commercial gears that prosecute this resource. Both vertical lines and longlines also jointly catch other snapper and grouper species, such as vermilion snapper, red grouper and gag. In 2011, 368 commercial fishing vessels landed about 3.24 million pounds (gutted weight) of red snapper with a dockside value of 13.8 million dollars (Agar *et al.* in press).

Although the fishery was first developed in the late 1840's, federal management began in 1984 with the implementation of the GOM Reef Fish Fishery Management Plan, which established a minimum size for red snapper of 13 inches in total length (Strelcheck and Hood 2007). Subsequently, in response to stock assessments that indicated the deteriorating condition of the red snapper resource, the Council began adopting increasingly stricter regulations. The use of quotas, limited access fishing permits, trip limits and closed seasons not only proved to be biologically unproductive because of

[1] Other studies have adopted data envelopment analysis (DEA) to estimate fishing capacity (see Table 1). Orea *et al.* (2005) discuss the limitations of DEA for conducting fisheries research.

continuing quota overages but was also economically wasteful due to excessive capital investments, derby fishing conditions and unsafe fishing practices (Waters 2001; Hood *et al.* 2007).

On January 1, 2007, the Council implemented the red snapper IFQ program to reduce OC and to eliminate, to the extent possible, the problems associated with derby fishing. Under the program, fishers can sell and lease their harvesting privileges, which entitle them to a share of the permissible catch (capped at 6.02 per cent). Unlike other countries, the US legislation defines IFQ shares as revocable harvesting privileges, which precludes shareholders from obtaining compensation if the privileges are limited or withdrawn.

Since the start of the IFQ program, there have been significant savings in capital and labour devoted to catching red snapper. Five-year pre- and post-IFQ averages show that after the implementation of the IFQs the fleet contracted by 29 per cent and that the number of days fished and crewdays decreased by 4 and 6 per cent, respectively (Agar *et al.* in press). In addition, the fishing season increased from a 5 year pre-IFQ average of 109 days to a year round fishery which afforded fishers greater flexibility to meet market demands. Fishers began taking longer but fewer trips which allowed them to increase their aggregate landings and diversify their catch mix. Moreover, there have been no quota overages and share and lease prices have increased rapidly (Agar *et al.* in press). Next we define the main concepts used in this article, followed by a presentation of our OC analysis and a discussion of our main findings.

3. Measuring fishing capacity, capacity utilisation and overcapacity

3.1. Fishing capacity

This study adopts the definition of fishing capacity put forth by the Food and Agriculture Organization (FAO). The FAO defines capacity as the potential (maximum) output that a fishing fleet could harvest given the current stock of capital and other fixed inputs, the state of the technology and the available biomass (FAO 1998). Thus, the measurement of capacity requires the estimation of a 'best practice' short-run production frontier (Orea *et al.* 2005).

At the vessel level, fishing capacity equals the maximum attainable output with the full utilisation (unrestricted use) of variable inputs given the existing capital and other fixed factors of production. Because establishing the level of full utilisation of variable inputs is not trivial, several alternative approaches have been proposed including: (i) identifying the maximum observed variable input levels of all vessels with similar fixed input endowments (Dupont *et al.* 2002; Felthoven 2002); (ii) identifying the theoretically maximum variable input usage levels (Felthoven *et al.* 2009); (iii) increasing the observed variable input levels by an *ad hoc* scalar, like 125 and 150 per cent (Felthoven *et al.* 2009); and (iv) selecting input levels based on the economic optimum of the fleet (Felthoven and Morrison Paul 2004) .

Another key issue affecting the measurement of capacity is TE. The FAO definition of capacity assumes that vessels operate efficiently. However, fishing operations are subject to significant levels of randomness and have limited ability to target desired species (Kirkley and Strand 1988; Agar and Sutinen 2004). Low catch levels may not always be due to technical inefficiency (TI) but also due to unmeasured factors outside of the fisher's control such as bad weather and luck (Felthoven and Morrison Paul 2004; Solís *et al.* 2013).

To investigate the impact of TE on capacity, we provide two sets of measures under different assumptions about TE. The first measure assumes full variable input use under existing TE levels, whereas the second measure assumes full variable input use under full (maximum) TE levels (i.e. vessels would be operating at the 'best practice' frontier). To operationalise these capacity measures, we provide two sets of metrics: C^{MAX}, C^{50} and C^{25} and $C^{\mathrm{TE,MAX}}$, $C^{\mathrm{TE,50}}$ and $C^{\mathrm{TE,25}}$, where the superscript MAX indicates that variable input levels are set at the highest level observed in the sample and superscripts 50 and 25 indicate that the variable inputs are increased by 150 and 125 per cent, respectively. If the variable input increment is greater than technically feasible, we arbitrarily set it at the highest level observed in the sample.[2] The TE superscript indicates that vessels operate under full TE; otherwise, they operate at their current TE levels. We believe that C^{MAX} is the most sensible measure of fishing capacity because it maintains the current level of TE while allowing for variable input increases to maximum observed levels within the fishery.[3] Thus, we use C^{MAX} as the benchmark capacity measure in this study.

This study also proposes an alternative strategy to compute fishing capacity estimates for a particular species within a multispecies framework. Under the standard approach, the observed landings of each species in a given period are multiplied by the inverse of the distance between the actual outputs and the capacity outputs of that vessel. Then, fleet-wide, species-specific capacity estimates are obtained by simply adding the individual capacity estimates for each species over all the vessels in the fleet (Felthoven 2002; van Hoof and de Wilde 2005). Because the volume and mix of the species caught (and, hence technological capacity measures) can vary significantly in response to exogenous factors (e.g. changing market and economic conditions, local and international policies and regulations), we submit that improved capacity estimates can be obtained by using temporally averaged (or weighted) landings rather than observed landings.

To illustrate the rationale behind this alternative weighting strategy, consider that a vessel decides to forgo fishing in a given period (say a month).

[2] Only 10 and 48 observations were modified when variable inputs were increased by 125 and 150 per cent, respectively.

[3] Previous studies have shown that IFQs have brought about marginal improvements on vessel-level TE in the short run (Brandt 2007; Pascoe *et al.* 2012; Solís *et al.* 2014).

Then, the true capacity output estimate should be the same as if this vessel had fished normally. By the same token, if a vessel had chosen not to target a particular species because the fish price was low (or fuel prices were high) during a given period, then the capacity output estimate of this species should not be zero, either. Because the traditional methodology does not control for exogenous factors, we posit that the estimation of sensible capacity estimates should also consider the use of historical weights. In the US GOM red snapper fishery, the introduction of the red snapper and grouper–tilefish IFQ programs and the Deepwater Horizon oil spill had a strong impact on fishers' targeting behaviour, which strengthens the case for using historical weights.[4]

3.2. Capacity utilisation and overcapacity

The concepts of CU and OC provide useful insights into the analysis of fishing capacity. In a single-species fishery setting, CU is defined as the ratio of actual output (Y) to capacity output (C), which indicates the proportion of the fishing capacity that is effectively utilised (Felthoven and Morrison Paul 2004). A ratio of less than one indicates the presence of excess capacity (EC; Kirkley *et al.* 2002). In other words, fishing firms have the potential for increasing production without having to incur major expenditures in new capital or equipment (Reid *et al.* 2005). Grafton *et al.* (2006) note that ratios below unity can also be caused by fixed input constraints. The inverse of the CU (i.e. 1/CU) indicates that amount of the catch could be increased if the existing capacity was used optimally (Kirkley *et al.* 2002).

In a multispecies fisheries setting, CU can be computed as the ratio of the aggregate output of each vessel if fully efficient (Y^{TE}) to the capacity output of each vessel assuming full efficiency (C^{TE}). After algebraic manipulations, CU can be shown to equal:

$$\mathrm{CU}^{\mathrm{TE}} = \frac{Y^{\mathrm{TE}}}{C^{\mathrm{TE}}} = \frac{Y/\mathrm{TE}}{Y/\mathrm{TE}^{\mathrm{C}}} = \mathrm{TE}^{\mathrm{C}}/\mathrm{TE}, \tag{1}$$

where TE^{C} is the inverse of the distance between the actual outputs and the capacity outputs, and TE is the efficiency of the vessel.

The OC is the difference between capacity and a desirable sustainable catch level such as maximum sustainable yield (MSY; Pascoe *et al.* 2003). In our study, capacity output of the fleet is obtained by aggregating the individual capacity estimates over all vessels in the fleet, and MSY is obtained from a recent stock assessment. OC exists when a fleet uses an excessive amount of fixed inputs to produce a desired catch level (Kirkley and Squires 1999).

[4] We calculated individual-level 5-year pre (2002–2006)- and post-IFQ (2007–2011) averages for each species or species group. Then, we simulated catches for each observation by multiplying the total catch by its corresponding historical species weights.

4. Methodology

In this study, we adopt the SDF method using an output orientation. The output distance function (ODF) measures the maximum amount by which an output vector can be proportionally expanded with a given input vector. Previous research indicates that output-oriented models are preferable to study fishing operations because fishers cannot readily change factors of production during the fishing trip (Orea *et al*. 2005).

To empirically estimate our model, we use the translog (TL) multioutput production frontier which has been shown to be a good approximation to a true ODF (Coelli and Perelman 1999).[5] This model can be written as follows:

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

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

A well-behaved ODF is homogeneous of degree 1 in outputs and is symmetric in parameters. Coelli and Perelman (1999) show that homogeneity can be imposed by normalising the function by an arbitrary output; and $\beta_{mn} = \beta_{nm}$ and $\beta_{kl} = \beta_{lk}$ for symmetry. Thus, to fulfil these theoretical requirements, Equation (2) is transformed to

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

[5] The TL functional form was selected over a Cobb–Douglas specification based on the results of generalised likelihood ratio tests.

Rewriting Equation (3) we obtain:

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

The concept of a stochastic frontier can then be introduced by defining the distance between each observation and the frontier as inefficiency (i.e. $ln\mathrm{D}_{\mathrm{o}i} = -u_i$) and adding a random noise term (v_i) into Equation (4). Consequently, the normalised TL output-oriented stochastic distance frontier (OSDF) function can be rewritten as:

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

where v_i, is assumed to be an independent and identically distributed normal random variable with a zero mean and constant variance, iid [N~(0, σ_v^2)]. v_i is a stochastic term which captures random events, and its variance, σ_v^2, is a measure of the importance of random shocks in determining variation in output. u_i, the inefficiency term, is non-negative, and it is assumed to follow a half-normal distribution.[6] The u_i are intended to capture differences in skill or efficiency across vessels. The model also includes a set of control variables (H) to account for extraneous factors affecting production. To facilitate the interpretation of the parameters, we transformed the left side of the equation to be ln y_1 rather than –lny_1 as suggested by Coelli and Perelman (1999). By doing so, the interpretation of the parameters is now comparable to those from standard production function models.

[6] A likelihood ratio test was used to determine the most suitable distribution for u.

Levels of TE can be estimated following Jondrow *et al.* (1982) as:

$$\begin{aligned} \mathrm{TE}_i = D_{oi} &= \exp(\mathrm{E}(-u_i)|v_i - u_i) \\ &= -\frac{\sigma_u \cdot \sigma_u}{\sigma} \cdot \left[\frac{f((v_i - u_i) \cdot \lambda/\sigma)}{1 - F((v_i - u_i) \cdot \lambda/\sigma)} - \frac{(v_i - u_i) \cdot \lambda}{\sigma} \right], \end{aligned} \tag{6}$$

where f and F represent the standard normal density and cumulative density functions, respectively. $\sigma^2 = \sigma_u^2 + \sigma_v^2$, $\lambda = \sigma_u/\sigma_v$. TE scores are bounded between 0 and 1. TE achieves its upper bound when a vessel is producing the maximum feasible output, given the available inputs and stock abundance.

To measure the capacity of a vessel, it is necessary to calculate v_i–u_i assuming that the variable inputs are fully utilised. That is, output levels and the fixed input usage are observed from the fishing activity of the fleet while variable input usage is increased to maximum potential levels. Consequently,

$$\begin{aligned} v_i - u_i = {} & \ln y_{1i} + \hat{\beta}_0 + \sum_{m=2}^{M} \hat{\beta}_m \ln\left(\frac{y_{mi}}{y_{1i}}\right) + 0.5 \sum_{m=2}^{M} \sum_{n=2}^{M} \hat{\beta}_{mn} \ln\left(\frac{y_{mi}}{y_{1i}}\right) \ln\left(\frac{y_{ni}}{y_{1i}}\right) \\ & + \sum_{m=2}^{M} \hat{\beta}_{tm} t \ln\left(\frac{y_{mi}}{y_{1i}}\right) + \sum_{k=1}^{K} \hat{\beta}_k \ln x_{ki} + 0.5 \sum_{k=1}^{K} \sum_{l=1}^{K} \hat{\beta}_{kl} \ln x_{ki} \ln x_{li} \\ & + \sum_{k=1}^{K} \hat{\beta}_{tk} t \ln x_{ki} + \sum_{k=1}^{K} \sum_{m=2}^{M} \hat{\beta}_{km} \ln x_{ki} \ln\left(\frac{y_{mi}}{y_{1i}}\right) + \sum_{j} \hat{\beta}_{hj} H_j. \end{aligned} \tag{7}$$

The expected value of u_i given v_i–u_i can be calculated using Equation (7). The capacity TE (TE^{C}) is the distance from the observed outputs to the maximum attainable production level assuming full utilisation of variable inputs and is calculated by $\mathrm{TE}_i^C = \exp(E(-u_i)|v_i - u_i)$. TE^{C} is bounded between zero and one. To obtain a capacity measure for each vessel, the observed outputs have to be multiplied by the inverse of TE^{C}. In doing so, we obtain the capacity of each vessel for all outputs.

5. Data and model specification

The data used in this study were obtained from the National Marine Fisheries Service (NMFS) Southeast Coastal Fisheries Logbook Program and the Permits Information Management Systems (PIMS) databases. The logbook database contains detailed trip-level information on landings and fishing effort, and the PIMS database contains information on vessel characteristics.[7] To avoid heterogeneous production biases, we bounded our analysis to those trips taken exclusively by vessels that used vertical lines, which accounted for over 95 per cent of the red snapper landings. In this study, we bounded our

[7] Full description of these databases are available at http://www.sefsc.noaa.gov/fisheries/.

analysis to 5 years before and after the implementation of the IFQ in 2007 (e.g. 2002–2011). Observations with missing or incomplete input and/or output data were also excluded from the analysis resulting in an unbalanced panel data of 63,270 observations on 835 distinct vessels.[8] Following Felthoven and Morrison Paul (2004), we aggregated our trip-level data into seasonal vessel-level observations (each year was divided into four quarters or seasons: January–March, April–June, July–September and October–December). The final data set contained 12,717 (seasonal vessel level) observations.

The empirical model included four outputs, three inputs and a set of control variables. The four outputs were specified as total quarterly landings of red snapper (y_1), other snappers (y_2), shallow-water groupers (SWG; y_3) and a residual or miscellaneous species group (y_4). Output levels are measured in pounds (gutted weight, g.w.), and y_1 was used to normalise the OSDF and to impose linear homogeneity in outputs. The factors of production included vessel length (x_1), number of fishing days (x_2) and crew size (x_3). Fishing days and crew size were measured as total counts for each season.

The model also controls for changes in stock levels, technical change, and seasonal and regional variability in production. A spawning biomass index for red snapper (stock) was used as a proxy of abundance to capture the influence of variations in stock size on catch rates (as in Felthoven and Morrison Paul 2004). The biomass data were provided by the NMFS. Quarterly dummy variables (Q_1, Q_2 and Q_3; Q_4 is the base quarter) were included to control for seasonal changes in fishing conditions, and fishing areas dummies were added to account for productivity differences across the Gulf region. Figure 1 shows the location of these geographical zones. Linear and quadratic time trends (t and t^2) were included to account for technical change. Table 2 presents key summary statistics of the harvesting activity.

6. Results and discussion

6.1. Model performance and characteristics of the technology

Output-oriented SDF estimates for the US GOM red snapper vertical line fleet are shown in Table 3. The parameter estimates of the first-order terms of both inputs and outputs display the expected signs suggesting that the OSDF specification is consistent with economic theory. In addition, the null hypothesis that TI does not exist (H_o: $\lambda = 0$) is rejected at the 1 per cent level favouring the adoption of a production frontier over the standard production function. The ratio of the standard error of u to that of v, λ, equals 2.04,

[8] It is important to indicate that only 75 of the original 63,345 observations for vertical liners were dropped from the analysis due to the lack of production data. Moreover, the original data are unbalanced panel because not all vessels participated in the fishery every year.

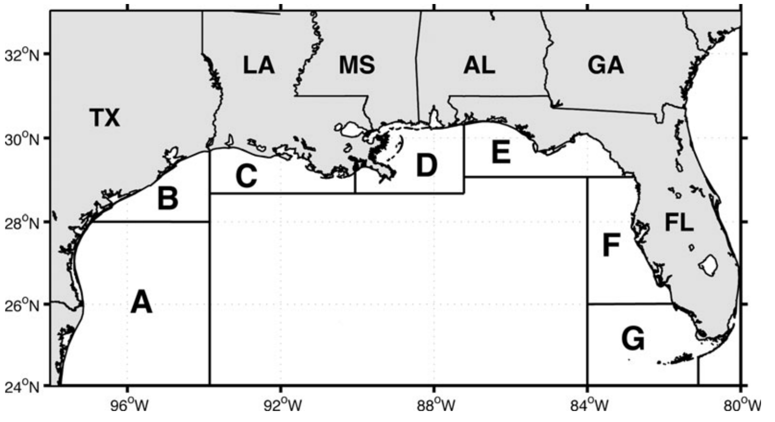

Figure 1 Fishing areas in the exclusive economic zone of the US Gulf of Mexico.

Table 2 Descriptive statistics

Variable	Unit	Parameter	Mean	SD
Red snapper landings	lbs/trip	y_1	496.64	1002.88
Other snappers landings	lbs/trip	y_2	361.43	880.57
Shallow-water groupers landings	lbs/trip	y_3	351.80	642.46
Other species landings	lbs/trip	y_4	249.05	741.93
Vessel length	feet	x_1	38.28	10.02
Days away	days	x_2	3.40	2.66
Crew size	count	x_3	2.69	1.27
Area A (base dummy)	dummy	Area A	0.02	—
Area B	dummy	Area B	0.10	—
Area C	dummy	Area C	0.10	—
Area D	dummy	Area D	0.24	—
Area E	dummy	Area E	0.33	—
Area F	dummy	Area F	0.19	—
Area G	dummy	Area G	0.02	—
Log RS stock	biomass	Stock	13.09	0.64
No. observations	—	—	63,270	—

indicating that skill (efficiency) is more important than random shocks in explaining production differences across fishing vessels.

Table 4 presents partial input and output distance elasticities and returns to scale (RTS) estimates for the entire 10-year period and for the 5 years preceding and following the IFQ program. At the sample mean, partial input distance elasticities were equal to 0.58 for crew size, 1.11 for fishing days and 0.74 for vessel length. These elasticities indicate that landings are more responsive to changes in trip duration than to changes in crew size. The results also show a positive relationship between vessel size and landings. Following the adoption of the IFQ program, there was a statistically significant decline in the magnitude of all the partial input distance elasticities probably due to the remaining fleet taking fewer but longer fishing trips.

Table 3 Parameter estimates of the output-oriented stochastic distance frontier model

Parameter†	Coefficient	SE
Constant	5.614***	0.436
Y_2	−0.156***	0.007
Y_3	−0.414***	0.005
Y_4	−0.155***	0.006
Y_2*Y_2	−0.064***	0.002
Y_3*Y_3	−0.087***	0.001
Y_4*Y_4	−0.073***	0.001
Y_2*Y_3	0.025***	0.001
Y_2*Y_4	0.021***	0.001
Y_3*Y_4	0.031***	0.001
x_1	0.857***	0.073
x_2	1.145***	0.017
x_3	0.610***	0.046
x_1*x_1	−0.612***	0.197
x_2*x_2	−0.167***	0.014
x_3*x_3	−0.494***	0.080
x_1*x_2	−0.068*	0.035
x_1*x_3	0.066	0.106
x_2*x_3	0.042**	0.021
Y_2*x_1	−0.077***	0.014
Y_2*x_2	−0.004	0.003
Y_2*x_3	0.014*	0.009
Y_3*x_1	−0.016	0.010
Y_3*x_2	−0.024***	0.002
Y_3*x_3	−0.009	0.006
Y_4*x_1	0.009	0.013
Y_4*x_2	0.018***	0.003
Y_4*x_3	0.023***	0.008
Y_2*t	−0.002	0.001
Y_3*t	−0.003***	0.001
Y_4*t	−0.005***	0.001
x_1*t	−0.023*	0.013
x_2*t	−0.006**	0.003
x_3*t	−0.006	0.008
Area B	0.206***	0.061
Area C	0.542***	0.077
Area D	0.241***	0.059
Area E	0.347***	0.084
Area F	0.431***	0.081
Area G	0.339***	0.079
Stock	0.068**	0.031
Q_1	−0.070***	0.023
Q_2	−0.053***	0.020
Q_3	−0.063***	0.021
t	−0.020*	0.012
t^2	0.004***	0.001
σ_u	1.113***	—
σ_v	0.546***	—
$\lambda = \sigma_{u/}\sigma_v$	2.038***	—
Log-likelihood	−15,881	—
N	12.717	—

$*P < 0.10$; $**P < 0.05$; $***P < 0.01$. †To impose linear homogeneity in outputs, the right-hand side outputs are normalised by red snapper (e.g. $Y_2 = y_2/y_1$).

Table 4 Partial distance input and output elasticities and RTS†

Elasticities	Whole sample	Pre-IFQ	Post –IFQ	Test of means‡
y_1	−0.26	−0.28	−0.24	0.000
y_2	−0.16	−0.15	−0.17	0.000
y_3	−0.42	−0.40	−0.44	0.000
y_4	−0.16	−0.17	−0.15	0.000
x_1	0.74	0.82	0.64	0.000
x_2	1.11	1.14	1.09	0.000
x_3	0.58	0.59	0.56	0.000
RTS	2.43	2.55	2.29	0.000

†Partial distance input elasticities: $\varepsilon_{ki} = \frac{\partial \ln D_{oi}}{\partial \ln x_k} = \beta_k + \sum_{k=1}^{K} \beta_{kl} \cdot \ln x_{ki} + \sum_{k=1}^{K} \beta_{tk} \cdot t + \sum_{m=2}^{M} \beta_{km} \cdot \ln y_{mi}$; Partial distance output elasticities: $\varepsilon_{mi} = \frac{\partial \ln D_{oi}}{\partial y_m} = \beta_m + \sum_{m=1}^{M} \beta_{mn} \cdot \ln y_{mi} + \sum_{m=1}^{M} \beta_{tm} \cdot t + \sum_{k=1}^{K} \beta_{km} \cdot \ln x_{ki}$; and return to scale: $\mathrm{RTS} = \sum_{k=1}^{K} \frac{\partial \ln D_{oi}}{\partial \ln x_k}$. ‡Test (*P*-values) before and after the implementation of the IFQs. IFQ, individual fishing quotas; RTS, returns to scale.

In contrast, partial output distance elasticities, which capture the share of each species (or species' group) relative to the aggregate landings, showed a statistically significant mixed pattern of change. This suggests that the composition of the landings became more diverse after the implementation of the IFQ program. Specifically, fishers began targeting more vermilion snapper and SWG. Table 4 also shows the presence of increasing RTS suggesting the presence of substantial OC (Asche *et al.* 2009).[9] However, the magnitude of the point estimates decreased by about 12 per cent (from 2.55 to 2.29) since the start of the IFQ program. We suspect that this statistically significant decline can be explained by decreases in the industry's long-run average cost structure brought about by the exit of marginal producers and regulatory easing (e.g. phasing out of trips limits and closed seasons). Nonetheless, the post-IFQ point estimate indicates that additional cost savings are possible if the fleet could readily adjust their size (Grafton *et al.* 2000). In other words, the fleet has yet to achieve an economically optimal configuration.

The OSDF model also captures important regional and seasonal differences. Fishing grounds off the coast of Louisiana were found to be the most productive, whereas those off the coast of Texas were found to be the least productive. The model also suggests that productivity levels increase in late winter and early spring to take advantage of the Lenten season.

6.2. The impact of IFQs on capacity, capacity utilisation and overcapacity

Now we turn to the examination of various capacity-related metrics which provide insight into the performance of the IFQ program. Table 5 presents

[9] Similar results are reported by Bjørndal and Gordon (2000), Felthoven *et al.* (2009) and Solı́s *et al.* (2014).

Table 5 Fleet capacity measures (1000's lbs. g.w. of red snapper)

Period†	Catch	C^{MAX}	$C^{TE,MAX}$	C^{25}	$C^{TE,25}$	C^{50}	$C^{TE,50}$
Entire period	3142	14,247	33,374	3739	8015	4357	9434
Pre-IFQ	3819	15,178	36,019	4547	9954	5294	11,693
Post-IFQ	2465	13,316	30,729	2931	6075	3420	7174
% change	−35.4	−12.3	−14.7	−35.5	−39.0	−35.4	−38.6

†Annual average capacity measures during the time period. IFQ, individual fishing quotas.

alternative capacity measures for red snapper (y_1) based on different assumptions described in Section 3.1. Predictably, capacity estimates that were based on the assumption of full TE ($C^{TE,k}$; for k equal MAX, 50 and 25) displayed higher magnitudes than those estimated under the existent level of TE (C^k). The magnitudes of the capacity estimates were 2.1–2.3 times higher across the same peer group (e.g. C^{MAX} versus $C^{TE,MAX}$). The ratios of the full TE capacity estimates to the reported red snapper landings in the sample were about 10.6 for $C^{TE,MAX}$, 3.0 for $C^{TE,50}$, and 2.6 for $C^{TE,25}$. Conversely, the ratios of the capacity estimates under the current TE levels relative to the reported red snapper landings in the sample were about 4.5 for C^{MAX}, 1.4 for C^{50}, and 1.2 for C^{25}.

The results in Table 5 also show that the pre- and post-IFQ quinquennial capacity averages declined significantly. Fleet capacity decreased between 12 and 39 per cent depending on the capacity measure considered. These results can be explained by the post-IFQ exit from the fishery of almost 30 per cent of the vessels in the sample.

Measures of CU are reported in Table 6. Because CU ratios are vessel-specific and the vessels are assumed to be fully efficient, we only report peer group averages. The magnitude of the peer group averages indicates the proportion of fishing capacity that is effectively used. CU ratios of less than unity indicate the presence of EC. The significant differences across peer groups can be explained by the low levels of variable input use. The inverse of the 10-year CU measures suggests that red snapper landings could be enhanced by 24 per cent if inputs levels were increased by 25% and by 49 per cent if inputs levels were augmented by 50 per cent. At full input utilisation, production levels could be increased by 361 per cent. The 5-year pre- and post-IFQ CU averages increased from a low of 0.5 per cent to a high of 6.3 per cent depending on the peer group. Regardless of the peer group

Table 6 Fleet average capacity utilisation (CU) measures

Period†	$CU^{TE,MAX}$	$CU^{TE,25}$	$CU^{TE,50}$
Entire period	0.217	0.804	0.669
Pre-IFQ	0.211	0.802	0.666
Post-IFQ	0.225	0.806	0.672
% change	6.3	0.5	0.8

†Average CU measures during the time period. IFQ, individual fishing quotas.

Table 7 Evolution of red snapper capacity and OC (1000's lbs. g.w.)

Year	Quota	Number of observations	Share of RS	C^{MAX}		OC	
				Historical weights	Observed weights	Historical weights	Observed weights
2002	4189	1476	0.38	16,764	18,749	12,575	14,560
2003	4189	1480	0.37	16,351	17,551	12,162	13,362
2004	4189	1567	0.35	15,139	15,554	10,950	11,365
2005	4189	1385	0.36	13,493	14,559	9304	10,370
2006	4189	1324	0.44	14,141	16,296	9952	12,107
2007	2986	1141	0.31	11,646	12,619	8660	9633
2008	2297	1127	0.25	11,416	10,996	9119	8699
2009	2297	1178	0.22	12,384	12,644	10,087	10,347
2010	3191	1019	0.38	15,872	19,527	12,681	16,336
2011	3300	1020	0.33	15,261	19,638	11,961	16,338
Pre- IFQ†	4189	1446	0.38	15,178	16,542	10,989	12,353
Post-IFQ	2814	1097	0.30	13,316	15,085	10,502	12,271

†Average values during the time period. IFQ, individual fishing quotas; OC, overcapacity.

considered, the CU measures indicate that the IFQ program had a modest success in reducing EC.

Table 7 shows benchmark capacity (C^{MAX}) and OC measures over time. Though both C^{MAX} measures declined, OC was still widespread 5 years after the adoption of the IFQ program. In other words, the size of the fleet in 2011 was substantially larger than necessary to harvest the permissible quota. Calculations suggest that about 75 vessels (or about one-fifth of the 2011 fleet) could have harvested the 2011 quota.[10] Moreover, assuming a fully recovered red snapper stock, OC levels would remain high since about 156 vessels (about 50 per cent of the 2011 fleet) could harvest the hypothetical quota.[11]

Finally, Table 7 compares C^{MAX} and OC estimates under the standard and the proposed historical weighting scheme. The results show that the use of historical weights produces capacity measures with smaller annual variability than the observed weights approach. In fact, the standard deviation for C^{MAX} using historical weights is 58.3 per cent smaller than the one obtained using observed weights (1945 and 3080, respectively). On average, the use of historical weights (with the exception of 2008) yielded lower capacity estimates. The pre- and post-IFQ quinquennial capacity averages show that capacity decreased by 12 per cent under the historical weighting scheme and by 9 per cent under the traditional weighting scheme.

[10] To estimate the optimum fleet size, we assumed that the representative vessel could utilise the maximum level of variable inputs at its existing TE levels, which would enable it to harvest 43,947 lbs (g.w.) of red snapper (i.e. 13,316,000 lbs (g.w.)/368 vessels). We also assumed 2011 red snapper commercial quota levels of 3,300,901 lbs. (g.w.).

[11] The red snapper stock is currently overfished but not undergoing overfishing. It was assumed that a fully recovered red snapper stock would yield a commercial quota of 6,846,847 lbs. (g.w.).

7. Summary and conclusions

Fisheries managers are progressively turning to IFQs to address the imbalance between available fish resources and the size of commercial fishing fleets. Yet, few empirical studies have examined the efficacy of this management tool. This paper assesses the impact of the US GOM red snapper IFQ program on the capacity of the commercial fleet and offers an alternative approach to estimate species-specific capacity measurements for multispecies fisheries.

Drawing on a SDF analysis, we find that fishing capacity decreased under the IFQ program. We estimated that the fishing capacity decreased between 12 and 39 per cent depending on the capacity measure considered. However, we consider that the lower value is the better estimate because it assumes that vessels operate at current levels of TE. We also find that the decline in capacity was mainly driven by a large number of vessels leaving the red snapper fishery. Many of the displaced vertical line vessels began harvesting other mid-water snappers, especially vermilion snapper, and shallow-water groupers like red grouper. Our results are consistent with a red snapper shareholders attitudes and perceptions survey, which reported that 65 per cent of the respondents did not make any major investments or disinvestments. Only 13 per cent of the shareholders reported making significant disinvestment (Boen and Keithly 2012). The results also show that CU increased marginally, suggesting that the IFQ program had moderate success limiting EC but OC levels remained high. We estimated that about one-fifth of the current fleet could harvest the entire 2011 quota and that about half of the current fleet could harvest the entire quota corresponding to a fully recovered red snapper stock.

Our results suggest that the use of the historical weights method produced capacity measures with smaller annual variability than the traditional observed weights approach. By adopting our proposed method, we can better control for annual variations unrelated to the technical characteristics of the fleet and resource abundance (e.g. market and economic conditions). Thus, it seems that our proposed approach offers a better representation of the physical capacity of a fishing fleet.

We also touch on two policy implications of our work. First, the sustained presence of an overdimensioned fleet suggests that the anticipated benefits of the IFQ program have not fully materialised. While understanding the reasons behind the delayed disinvestment was beyond the scope of the paper, Nøstbakken (2012) conjectures that the adjustment of capital can be sluggish because fishing firms that were grandfathered do not take into account the full opportunity cost of their gifted quotas, at least in the short run. Also, currently most red snapper fishers do not perceive that OC continues to be a problem, which lessens the incentive to devise rules to address this challenge (Assane Diagne[12], pers. comm., 2014). Hence, expediting efficiency gains may

[12] Dr. A. Diagne is the senior economist of the Gulf of Mexico Fishery Management Council, Tampa, Florida.

require government intervention. Pascoe *et al*. (2012) suggest that combining IFQs with a buyback program can accelerate the achievement of an economically optimal fleet configuration.

Second, while our research suggests that capacity in the US GOM red snapper fishery has declined, the actual net reduction may be lower because many of the displaced fishers shifted their harvesting activities to other reef-fish species rather than retiring (scrapping) their vessels. This undesired outcome suggests that capacity assessments should be more encompassing not only to provide meaningful OC estimates to better gauge the performance of IFQ programs but also to alert decision-makers about the potential spillover effects of these types of programs on closely related fisheries. Finally, we want to underscore that IFQs are not the only management instrument that provides sound incentives to reduce excessive investments levels and promote the sustainable use of fishery resources. Other institutional arrangements such as comanagement may also prove fruitful. Interestingly, Wilson (2010) observes that proponents of comanagement have noticed that a number of community and/or industry-based fisheries comanagement regimes are turning on their own initiative to IFQ-like arrangements.

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