Measuring the initial economic effects of hurricanes on commercial fish production: the US Gulf of Mexico grouper (Serranidae) fishery

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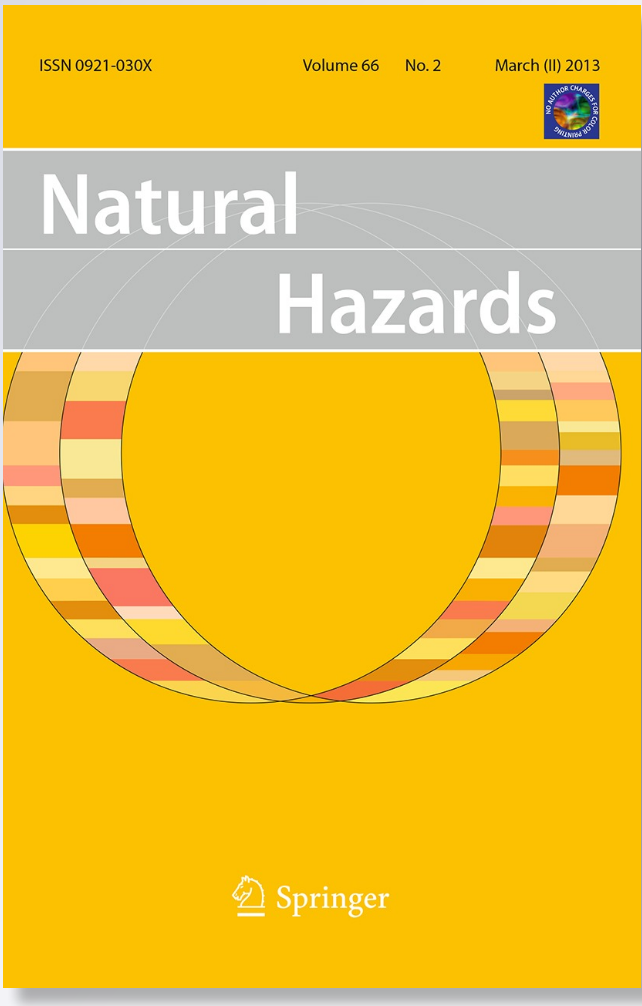

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ORIGINAL PAPER

Measuring the initial economic effects of hurricanes on commercial fish production: the US Gulf of Mexico grouper (*Serranidae*) fishery

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Abstract A stochastic production frontier was used to measure the initial (i.e., bi-weekly) economic effects of hurricanes on commercial grouper (*Serranidae*) production in the Exclusive Economic Zone of the United States Gulf of Mexico from 2005 to 2009. We estimated the economic effects of productivity losses associated with specific hurricanes on the commercial grouper fleet. We also calculated the economic effects due to productivity losses during an entire hurricane season at the regional level. The empirical model controls for input levels as well as other factors affecting production to isolate the initial economic effect caused by hurricanes from other non-weather-related factors. The empirical results revealed that hurricanes striking the Gulf of Mexico coastline from 2005 to 2009 had a negative effect on the production of the commercial grouper fleet. The results also demonstrated the relative importance of inputs and regulations on fish production.

Keywords Hurricanes · Economic damage · Commercial fisheries · Stochastic production frontier · US Gulf of Mexico

The opinions expressed in this study are those of the authors and do not necessarily represent the views or policies of the University of Miami, the National Oceanic and Atmospheric Administration, or the University of Castilla-La Mancha.

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1 Introduction

In basic economic terms, production refers to the process by which a firm uses technology and skill to transform inputs into outputs. In commercial fisheries, firms make technological and behavioral decisions (e.g., gear choice, where to fish) to transform a combination of inputs (e.g., fuel, labor, and capital) into harvests of marketable fish species. Fishers often face production uncertainty in the form of variable harvest rates due to biological and ecological factors, regulatory mandates, as well as from climate variability and severe weather. The present study focused on this last issue, that is, changes in commercial fish production (harvest levels) and the resultant financial effect brought about by severe weather events such as hurricanes.

When hurricanes strike coastal communities, commercial fishers may initially suffer economic hardship due to lost fishing time during the immediate aftermath of the storm as well as in response to pre-hurricane warnings and conditions. Nidhiprabha (2007) argues that evaluating the initial impacts of natural disasters is important because the long-run economic effect of these events can be diluted over time due to exogenous factors (e.g., governmental aid, market adjustments, etc.); whereas the immediate economic displacement can be severe enough to affect the sustainability of individual operators.

Although the impact of hurricanes on marine ecosystems and coastal areas is well documented (e.g., Burgess et al. 2007; Dolloff et al. 1994; Conner et al. 1989, among others), few studies have specifically analyzed the disruption to the commercial fishing industry when these storms strike. In general, hurricanes do not appear to generate long-term changes with respect to fish abundance, but they have been known to cause significant short-term biological effects by redistributing species or forcing them to migrate (Burgess et al. 2007; NMFS 2007). Dolloff et al. (1994) indicate that disturbances caused by hurricanes on fish habitats can have significant temporary impacts on the fish population; but, the composition and distribution of the affected species should return to normal after a few months. If this is the case, fishers may have trouble locating and subsequently harvesting fish which would reduce the productivity of the fleet.[1]

After a hurricane strikes, how can one measure the economic effect on the fishing industry? In the past, two main approaches have been utilized: revenue comparison and time series analysis. A comparison of ex-vessel industry revenue (primary producer sales) from the affected year to historical averages provides a measure of the residual economic effect due to an external event such as a hurricane. Revenue figures are relatively easy to calculate from self-reported or dealer-reported landings. The methodology is straightforward, and the effort required to measure economic effects is minimal. However, comparison of revenues in this manner may not identify a causal effect between changes in revenue and the hurricane event. Trends in annual fishery landings can be affected by an array of biological, ecological, and regulatory factors; thus, average revenue comparisons may not always correlate the effect of the hurricane to changes in production of the commercial fleet especially in the near term.

Time series analysis may also be used to measure the effect of a hurricane on commercial landings. Intervention analysis (Box and Tiao 1975) can be used to identify and quantify non-random changes in the time series of commercial landings due to an external

[1] In this study, we focus on the effect of hurricanes on fish production; however, hurricanes may also impact the commercial sector by damaging shore-side infrastructure, including boat yards, ice houses, processors, bait and tackle shops, seafood dealers, and repair shops, leading to support and supply chain problems which would further reduce landings and consequently lead to a loss of income.

event. Intervention analysis is an extension of a class of time series models where the variable of interest (e.g., commercial landings) follows an autoregressive-integrated-moving average (ARIMA) process which linearly links values of the variable (e.g., monthly totals of landings) to past values plus random shocks. Although the time series approach can identify non-random shocks related to hurricanes, the methodology has some drawbacks if used to measure economic effects. First, the approach does not allow the analyst to calculate the change in revenue within the ARIMA model; thus, a second-stage calculation of revenue as discussed above is still needed. Second, the model is data sensitive. The time intervals must be equally spaced with no missing data. Consequently, data must be aggregated to run the model, losing any vessel-level or trip-level information.

Using this last methodology, Burgess et al. (2007) identify structural changes in the time series of landings for the commercial blue crab fishery in North Carolina, following the 1999 hurricane season. The study shows that heavy rainfall produced by hurricanes Dennis and Floyd caused a "flushing" effect which redistributed the crabs into large aggregations producing record harvests for the fishing season of 1999. Coincidentally, the statewide catch productivity increased 369 % above the average for the previous 10 years. This suggests that a direct relationship exists between industrial productivity and harvest rates. In other words, positive or negative changes in industry revenue (economic effects) can be directly attributed to changes in the productivity of firms affected by the hurricane after accounting for extraneous factors.

The goal of the present study was to assess the initial economic effects of hurricanes on commercial fisheries by identifying changes to production (and, hence, income) in the time period directly before and after landfall of the storm. To achieve this goal, we proposed a stochastic production frontier (SPF) model to measure the change in ex-vessel revenue during the initial 2-week time period (i.e., pre-hurricane warnings and immediate aftermath) when the commercial fishing industry may be affected by a hurricane. The SPF method is based on an econometric (parametric) specification of a production frontier. A production frontier defines the technological relationship between the level of inputs and the resulting level of outputs of the "best practice" firms in an industry (Bravo-Ureta et al. 2007; Greene 2008). Thus, it represents the maximum potential output or total harvest for a given set of inputs. The SPF implemented in this study controls for the use of inputs as well as for other variables affecting industrial production (e.g., regulations, seasonality, and technical change). By controlling for these variables, we were able to isolate the initial economic effect on commercial fishers caused by hurricanes from other non-weather-related factors.

In a case study, we applied the methodology to the grouper sector of the US Gulf of Mexico reef fish (GOMRF) fishery which was affected by numerous hurricanes from 2005 to 2009. Two alternative and complementary model specifications for our SPF were used (1) to assess the marginal effects of hurricanes on fish production at the fleet level and (2) to estimate the economic effects of a hurricane season on regional sub-components of the fleet. Our findings showed that hurricanes striking the US Gulf of Mexico coastline from 2005 to 2009 had a negative effect on grouper production and hence industry revenue. The results also revealed the relative importance of inputs on fish production and the effects of regulations on harvest levels. Because the SPF methodology calculates a measure of foregone revenue that is directly related to storm impacts and generates a description of the underlying technology of the fleet, the production approach detailed in this paper provides an analytical framework for future evaluations of the economic impacts of natural disasters or other rare events.

2 Fleet and data description

2.1 The GOMRF commercial fleet

The GOMRF fleet harvests valuable fishery resources from the Exclusive Economic Zone (EEZ) off the southern US coastline between Texas (TX) and the Florida (FL) Keys.[2] The GOMRF fleet is defined as vessels owning permits that allow for the harvest/possession of quantities of reef fish caught in excess of the recreational bag limits for those species in the US Gulf of Mexico EEZ. There are 31 reef fish species in the management unit for the Fishery Management Plan for the Reef Fish Resources of the Gulf of Mexico, and commercial GOMRF trips commonly land multiple species. Primary gears include vertical line, bottom longline, and diving. We calculated that from 2005 to 2009, 1,354 federally permitted vessels, primarily targeting reef fishes, mackerels, and sharks, completed 47,777 trips in the US Gulf of Mexico EEZ, harvesting approximately 77 million pounds of seafood product estimated at $209 million dockside. Over this time period, 996 of these vessels completed 24,438 trips where the GOMRF species group that produced a plurality of trip revenues was either shallow-water groupers[3] (SWG) or deep-water groupers[4] (DWG). The SWG and DWG species groups accounted for approximately $90 million and $18 million of industry revenue in the GOMRF fishery during this period, respectively. Because the grouper sector of the GOMRF commercial fleet contributed significantly to economies of fishing communities along the Gulf Coast from 2005 to 2009, it was selected as the focus of this study.

2.2 Data

For this study, the grouper sector was defined as all trips that landed at least one pound of SWG or DWG species and were completed by vessels that reported at least one trip from 2005 to 2009 where the highest revenue-producing species was classified as SWG or DWG.[5] Trips completed by these vessels that did not register any landings of SWG or DWG were not included in the definition of the grouper sector. Likewise, trips completed by vessels that primarily caught other GOMRF species or only caught groupers incidentally were not considered part of the grouper sector.

The National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NMFS) requires vessels participating in the GOMRF commercial fishery to submit a record for each trip (Southeast Coastal Fisheries Logbook Trip Report Form) to

[2] Federal waters encompassing the US EEZ in the Gulf of Mexico extend to 200 nautical miles offshore from the nine-mile seaward boundary of the states of FL and TX, and the three-mile seaward boundary of the states of Alabama, Mississippi, and Louisiana.

[3] SWG species include red (*Epinephelus morio*), black (*Mycteroperca bonaci*), gag (*Mycteroperca microlepis*), yellowmouth (*Mycteroperca interstitialis*), and yellowfin (*Mycteroperca venenosa*) groupers, red (*Epinephelus guttatus*) and rock (*Epinephelus adscensionis*) hinds, and scamp (*Mycteroperca phenax*).

[4] DWG species include speckled hind (*Epinephelus drummondhayi*) and snowy (*Hyporthodus niveatus*), yellowedge (*Hyporthodus flavolimbatus*), warsaw (*Hyporthodus nigritus*), and misty (*Hyporthodus mystacinus*) groupers.

[5] Due to the multispecies nature of the GOMRF fishery, it is difficult to exclusively link GOMRF operators to the harvest of a single species group. Thus, it is more practical to define a sector (e.g., grouper) of the GOMRF fishery by homogenous trips rather than heterogeneous vessels.

the NMFS Southeast Fisheries Science Center in Miami, FL.[6] Required information includes the gear used, fishing effort, location, depth, quantity of each species landed, departure and offloading ports and dates, and dealer information. In 2005, variable cost (e.g., fuel, bait, and ice) and input usage questions were added to the logbook trip form. Approximately 25 % of GOMRF permit owners were selected each year by a stratified random sample based on primary gear used and primary region of landing to report this economic information, with volunteer submissions accepted as well. Additionally, individual Gulf states collect information through marine fisheries "trip ticket" programs from permitted dealers who maintain records of purchases of saltwater products. Data reported to state trip ticket programs are similar to data collected by the Logbook Program with the inclusion of per-pound prices for each species purchased. Trip ticket information is summarized in the NMFS Accumulated Landings System and was used to calculate average prices which were subsequently merged with self-reported landings from logbook trip reports by year, month, species, and state to estimate ex-vessel trip revenue. Landings, effort, and economic data were further supplemented with vessel characteristics information collected through the federal permit application process by the NMFS Southeast Regional Office's Constituency Services Branch in St. Petersburg, FL. The estimation of our SPF model requires information regarding inputs used (variable expenses) which was available for 12,658 trips taken by 673 unique vessels.[7] These trips comprised the studied sample of the grouper sector of the GOMRF commercial fishery. Table 1 compares descriptive statistics for the sampled fleet to those for the population of vessels that participated in the grouper fishery from 2005 to 2009. Both datasets display comparable statistics, suggesting that the studied sample is a good representation of the population.

Figure 1 presents output levels (bi-weekly ex-vessel revenue) for the studied sample between January 2005 and December 2009. To account for seasonality, we de-trended the data using quarterly averages.[8] This figure also includes all hurricanes affecting the studied area during that time period. Figure 1 shows possible evidence of a negative relationship between hurricanes and ex-vessel revenue generated by commercial harvests. The following sections describe the methodology and the empirical models used in this study and define the variables included in the analysis.

3 Methodology and empirical model

3.1 Stochastic production frontier

To study the effect of hurricanes on production in commercial fisheries, we used the SPF method developed by Aigner et al. (1977). Kumbhakar and Lovell (2000) argue that when

[6] Information about the Logbook Program and a copy of the trip report form is available at http://www.sefsc.noaa.gov/fisheries/reporting.htm.

[7] Commercial fishing for grouper in TX is mainly a deepwater activity represented by a relatively small number of high-volume trips; therefore, trips landing in TX were dropped from the analysis, as were trips where catch was landed away from the US Gulf Coast (i.e., inland FL, east FL or Georgia).

[8] We de-tended the data used to plot Fig. 1 to isolate the effect of hurricanes on revenues from seasonal variability. However, it is important to indicate that the empirical model used in this study, explicitly accounts for seasonality and other factors affecting production. Thus, the data used in the estimation of our production models were not de-trended.

Table 1 Comparison of trip-level descriptive statistics for the sample and population of trips conducted by the grouper sector of the GOMRF fishery from 2005 to 2009

Variable	Sample ($n = 12{,}658$)		Population ($n = 31{,}737$)		Test of means (*t test*)
	Mean	Std Dev	Mean	Std Dev	
No. of Vessels	673	–	966	–	–
Vessel Length (ft)[a]	38.6	9.1	37.9	9.2	7.26
Crew	2.5	1.0	2.6	1.1	8.87
Days	4.8	3.6	4.9	3.7	2.60
Expenses ($2009)	3,077	4,873	N/A	N/A	–
Pounds landed					
SWG	916.6	1,390.6	933.7	1,412.8	1.15
DWG	125.3	620.9	145.9	677.6	2.29
Tilefishes	50.7	425.3	56.8	470.5	1.27
Year					
2005	0.22	–	0.22	–	–
2006	0.31	–	0.22	–	–
2007	0.17	–	0.19	–	–
2008	0.15	–	0.19	–	–
2009	0.15	–	0.18	–	–
Region					
LA	0.08	–	0.05	–	–
ALMS	0.07	–	0.02	–	–
ECFL	0.21	–	0.21	–	–
BBFL	0.17	–	0.20	–	–
WCFL	0.32	–	0.40	–	–
SWFL	0.16	–	0.12	–	–
Season					
Quarter 1	0.25	–	0.23	–	–
Quarter 2	0.26	–	0.31	–	–
Quarter 3	0.26	–	0.28	–	–
Quarter 4	0.24	–	0.18	–	–
Primary gear					
Vertical lines	0.75	–	0.75	–	–
Bottom longline	0.17	–	0.19	–	–
Other gears	0.09	–	0.06	–	–

Region: *LA* Louisiana, *ALMS* Alabama and Mississippi, *ECFL* the Emerald Coast of Florida (FL), *BBFL* the Big Bend of FL, *WCFL* west central FL, *SWFL* southwest FL, and the FL Keys. *Species*: *SWG* shallow-water groupers, *DWG* deep-water groupers

[a] Statistics for vessel length were calculated using the number of unique boats and did not include weightings by any variables such as number of trips, effort level, or pounds landed

dealing with natural resources, the SPF method exhibits major strengths over deterministic techniques, such as data envelopment analysis, since it can incorporate stochastic noise and can accommodate traditional hypothesis testing. Using a generalized production function and panel data, the SPF method can be depicted as follows:

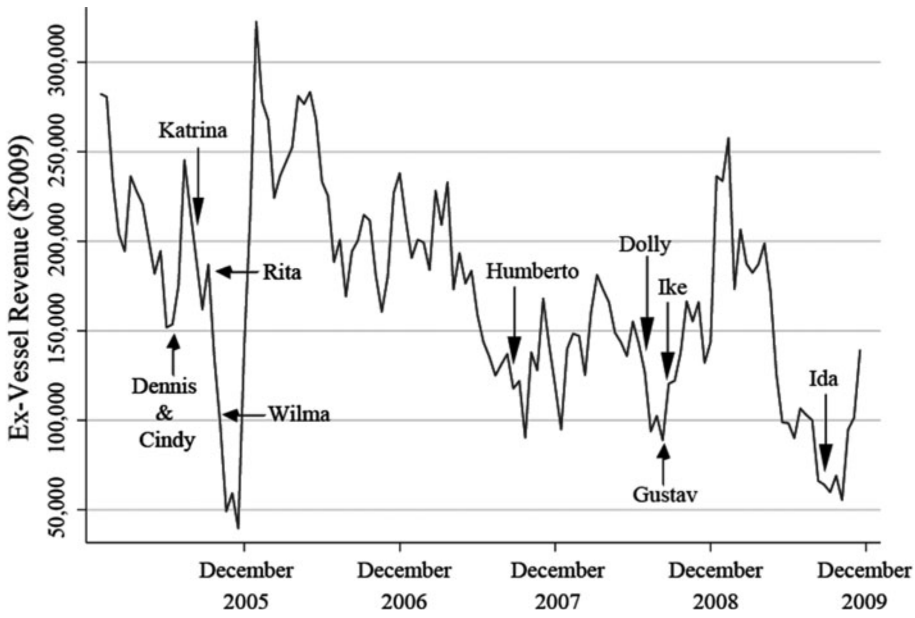

Fig. 1 De-trended bi-weekly ex-vessel revenue generated on trips by the grouper sector of the GOMRF fishery including hurricanes that affected the area from 2005 to 2009. *Source*: elaborated by the authors using data provided by the NMFS' Logbook Program

$$y_{it} = f\left(x_{jit}\beta_{\mathrm{j}}\right)\exp(\varepsilon_{it}) \tag{1}$$

where y represents output, x is a vector of inputs, β is a vector of unknown parameters, and ε is the error term. The subscripts j, i, and t denote the inputs, production unit, and time, respectively.

In this formulation, the error term is composed of two independent components, $\varepsilon_{it} = v_{it-}u_{it}$. The first element, v, is a random variable representing noise and other stochastic shocks entering the definition of the frontier. This term is assumed to be an independent and identically distributed normal random variable with mean of zero and constant variance, iid [$v \sim N(0,\sigma_v^2)$]. The second component, u, captures the distance of the observed output to the frontier output, namely, technical inefficiency. The inefficiency term u is non-negative and, in this study, follows an exponential distribution.[9]

3.2 Empirical specification

For the empirical analysis, we estimated two alternative SPF model specifications using a translog functional form:[10]

Model 1 (hurricane-specific effects on fleet-wide harvests):

[9] Based on a likelihood ratio test the exponential distribution showed better fit to the data compared to the truncated- and half-normal distributions.

[10] Preliminary comparisons led to the rejection of the Cobb-Douglas functional form.

$$\ln Y_{it} = \beta_0 + \sum_{j=1}^{3} \beta_j lnX_{jit} + \frac{1}{2}\sum_{j=1}^{3}\sum_{k=1}^{3} \beta_{jk} lnX_{jit} lnX_{kit} + \xi L_{it} + \sum_{s=1}^{9} \theta_s H_s + \sum_{r=1}^{5} \delta_r Z_r + \sum_{m=1}^{3} \varphi_m Q_m + \eta T + \sum_{p=1}^{3} \tau_p C_p + v_{it} - u_{it} \quad (2)$$

Model 2 (hurricane season effects on regional economies):

$$\ln Y_{it} = \beta_0 + \sum_{j=1}^{3} \beta_j lnX_{jit} + \frac{1}{2}\sum_{j=1}^{3}\sum_{k=1}^{3} \beta_{jk} lnX_{jit} lnX_{kit} + \xi L_{it} + \sum_{n=1}^{5}\sum_{i=1}^{6} \omega_{ni} N_{ni} + \sum_{r=1}^{5} \delta_r Z_r + \eta T + \sum_{p=1}^{3} \tau_p C_p + v_{it} - u_{it} \quad (3)$$

Because tropical storms have both temporal and spatial effects, the data were aggregated accordingly. Specifically, the dependent variable, *Y*, measured the bi-weekly[11] (*t*), ex-vessel revenue of total catch landed by one of six regional sub-components (*i*) of the grouper sector of the GOMRF fleet.[12] The geography of these sub-components corresponded to the six levels of the regional dummy variable (*Z*) described in the next paragraph. Both empirical models included three inputs (*X*) which were measured as the total bi-weekly quantities employed by vessels in each of the sub-components. The three inputs were the number of crew (*Crew*), the number of fishing days (*Days*), and total variable operating costs (*Expenses*) which was defined as the sum of the cost of fuel, bait, groceries, and miscellaneous variable inputs. All monetary values were adjusted for inflation and expressed in 2009 US dollars ($). The average length (*L*) of the vessels for each sub-component during each 2-week period was included to represent the fixed factor capital and control for vessel size. A similar input mix can be found in Kompas and Che (2005).

Based on NMFS' sampling stratification procedures for expense reporting and data availability, the studied area was divided into six landing regions (*Z*): LA: Louisiana; ALMS: Alabama and Mississippi; ECFL: the Emerald Coast of FL which includes Gulf, Bay, Walton, Okaloosa, Santa Rosa, and Escambia Counties; BBFL: the Big Bend of FL which includes Dixie, Taylor, Jefferson, Wakulla, and Franklin Counties; WCFL: west central FL which includes Sarasota, Manatee, Hillsborough, Pinellas, Pasco, Hernando, Citrus, and Levy Counties; and SWFL: southwest FL which includes Collier, Lee, Charlotte, and Monroe Counties including the FL Keys. SWFL was defined as the base level for *Z*. As indicated, TX was dropped from the analysis due to lack of observations.

To assess the initial effect of a hurricane on commercial harvests at the fleet (industry) level, a hurricane-specific dummy variable (*H*) was incorporated into Model 1.[13] By including a dummy variable with levels for every hurricane that impacted the Gulf Coast from 2005 to 2009, we accounted for each storm's intrinsic characteristics, such as category, path, and duration. A description of the intrinsic characteristics and tracking chart of all the hurricanes affecting the studied area during the studied period are presented in

[11] We selected a two-week time frame to measure the initial impact of a hurricane, including pre-hurricane (i.e., warnings and watches) and post-hurricane effects.

[12] The data aggregation implemented in this study reduced the number of observations to a potential 780 combinations (26 bi-weeks × 6 sub-components × 5 years). Harvests were not observed for all sample points; thus, the final number of observations equaled 624.

[13] Solís and Letson (2013) argue that the omission of climatic conditions when estimating production models could lead to biased estimates.

Table 2 Description of hurricanes affecting the US Gulf of Mexico during the Atlantic seasons from 2005 to 2009

Storm name	Date of landing in the continental US	Highest category at landfall	Region affected (category)
Cindy	7/6/2005	1	LA(1)
Dennis	7/10/2005	3	ECFL(3), AL(1)
Katrina	8/29/2005	3	LA(3), MS(3), AL(1)
Rita	9/24/2005	3	LA(3),TX(2)
Wilma	10/24/2005	3	SWFL(3)
Humberto	9/13/2007	1	TX(1), LA(1)
Dolly	7/23/2008	1	TX(1)
Gustav	9/1/2008	2	LA(2)
Ike	9/13/2008	2	TX(2), LA(1)
Ida	9/11/2009	2	LA(TS), AL(TS)

Highest category based on the Saffir-Simpson Scale: Cat 1 = (Wind Speed (WS): 74–95 mph), Cat 2 = (WS: 96–110mph), Cat 3 = (WS: 111–129 mph), TS = tropical storm. *States*: *AL* Alabama, *ECFL* Emerald Coast of Florida (FL), *LA* Louisiana, *MS* Mississippi, *SWFL* southwest FL, *TX* Texas

Table 2 and Fig. 2, respectively. This information was obtained from the National Hurricane Center.[14] Since hurricanes Cindy and Dennis struck the continental US just 4 days apart, a single level of H was included for these two storms. Alternatively, in Model 2, we included a new dummy variable (N) which represented all hurricanes in each year (n) (whole hurricane season) from 2005 to 2009 for each regional sub-component (i) of the Gulf grouper sector. This alternative model specification measured the effect of each hurricane season on regional economies in terms of changes in commercial harvests.

Following Alvarez and Schmidt (2006), we included a quarterly dummy variable (Q) to capture the seasonal changes of the fishing stock in Model 1. Since Q had the potential to pick up some of the hurricane effects (most hurricanes were concentrated in Quarter 3), a restricted version of Model 1, omitting seasonal variability, was also estimated. In the unrestricted model, Quarter 3 was defined as the base level for Q. Another factor hypothesized to affect production levels of the grouper fleet was the enactment of federal regulations driven by environmental concerns (Cai et al. 2005). During the studied period, the NMFS enforced closures in Gulf waters to reduce overfishing and to facilitate sustainable fisheries development. Therefore, both models included a dummy variable to control for closures (C) due to quota restrictions for SWG and DWG as well as tilefishes (*Malacanthidae*), which were frequently caught along with groupers. In May 2009, the use of bottom longline gear was prohibited east of Cape San Blas, FL, shoreward of the 50-fathom contour to protect sea turtles (*Cheloniidae* and *Dermochelyidae*).[15] Table 3

[14] Comprehensive information on each hurricane, including synoptic history, meteorological statistics, casualties, and damages, and the post-analysis best track can be found at the National Hurricane Center website (http://www.nhc.noaa.gov/pastall.shtml).

[15] From 2005 to 2008, the commercial harvest of gag, black, and red grouper was prohibited from February 15 to March 15 to protect spawning aggregations of gag. This regulation was repealed before the 2009 fishing season. Additionally, multi-tiered trip limits were in effect from March 2005 to February 2006. Dummy variables to control for the seasonal closures and trip limits were tested, and their coefficients were found to not be statistically different than zero. Thus, they were excluded from the final definition of levels for the regulatory dummy variable (C).

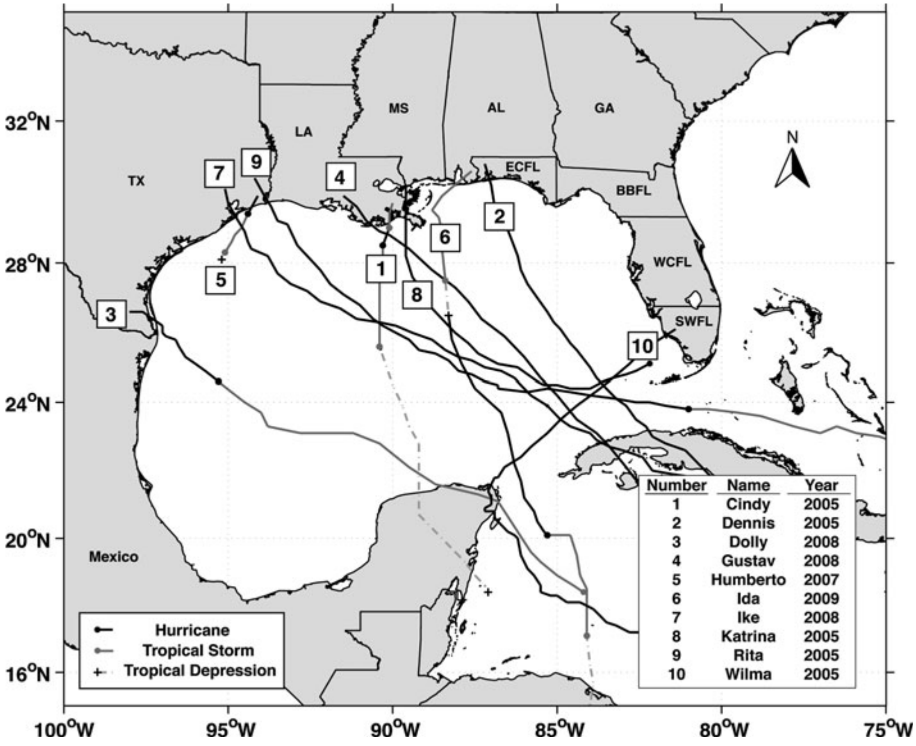

Fig. 2 Atlantic hurricane seasonal tracking chart (2005–2009). *Source*: elaborated by the authors using data obtained from National Hurricane Center

Table 3 Regulatory closures for the GOMRF fishery from 2005 to 2009

Years	Closure			
	Shallow-water grouper—Quota	Deep-water grouper—Quota	Tilefish—Quota	Emergency closure of West Florida shelf
2005	October 10	June 23	November 21	–
2006	–	June 23	July 22	–
2007	–	June 23	July 22	–
2008	–	May 10	May 10	–
2009	–	June 27	May 15	May 18–October 28

presents closure dates for these quota species and for the emergency closure of FL waters in 2009.[16] Lastly, we introduced a linear time trend (T) to account for technical change with a base year of 2005. Table 1 presents trip-level descriptive statistics and frequencies for the variables used in this study.

[16] The studied sample was selected from a period prior to the implementation of the Grouper-Tilefish Individual Fishing Quota (IFQ) Program. Thus, the IFQ regime did not affect the studied sample.

We used the maximum likelihood (ML) technique to estimate the empirical models. ML estimation produces consistent parameter estimates for the SPF. Following common practice, we normalized all variables by their geometric mean (GM) prior to estimation; thus, the first-order coefficients can be interpreted as partial production elasticities at the GM (Kumbhakar and Lovell 2000).

3.3 Economic damage assessment

As indicated, two alternative model specifications were used to measure the effect of hurricanes on commercial fish production. First, we analyzed the effect of each hurricane on the total production level of the commercial fleet targeting SWG and DWG in the GOMRF complex (Model 1). To do so, a hurricane-specific dummy variable (H) was incorporated into the model as described above. Since the seasonal dummy variable (Q) could potentially capture some of the effect of hurricanes on production, the economic analysis of the commercial fleet was performed using the restricted specification, which omitted the seasonal effects in the specification of the production frontier. Using the ML estimates of the hurricane-specific coefficients in the restricted model, we computed the marginal effect (ME) of each hurricane on production in terms of foregone ex-vessel revenue. In this study, the MEs measure the percentage change in the total value of bi-weekly ex-vessel revenue due to the impact of a hurricane. Thus, the MEs are the structural links connecting productivity losses due to a hurricane, and the predicted losses in ex-vessel revenue that are necessary to measure economic effects to industry. Following Alvarez and Schmidt (2006), the MEs were estimated by $e^{\hat{\theta}_s} - 1$, where e is the exponential function, and $\hat{\theta}_s$ is the estimated coefficient of a level of H (a specific hurricane). To calculate fleet-level economic effects in monetary terms, we used the following approach. First, we predicted the bi-weekly frontier output (ex-vessel revenue) for the whole GOMRF grouper sector assuming that no hurricanes impacted the fleet ($H_s = 0$). Second, in the same manner, we predicted the frontier output for the fleet incorporating the effect of each hurricane ($H_s = 1$). The difference between these two values (predicted bi-weekly ex-vessel revenue with and without the presence of hurricanes) was interpreted as the initial economic displacement experienced by the sampled grouper sector due to the effects of a hurricane on fish production. Finally, the economic loss was extrapolated to the entire grouper sector for an estimate of economic effects.

The second model specification analyzed the economic effects associated with each Atlantic hurricane season for regional sub-components of the GOMRF grouper fleet (Model 2), thus showing the spatial distribution of expected changes in industry productivity and revenue. Regional economic effects were measured in monetary terms using the following approach. First, we computed the annual predicted frontier output for each regional sub-component (i) of the fleet, assuming no hurricanes impacted the area during a given fishing season ($N_{ni} = 0$). The annual predicted output was computed by aggregating the estimates of ex-vessel revenue associated with each bi-week harvest period of a given year assuming that $N_{ni} = 0$. Quarterly mean values for X and L were used in the estimation to account for seasonality in the use of inputs. Second, in the same manner, we predicted output at the regional level with hurricane impacts, setting $N_{ni} = 1$ when a hurricane affected a regional sub-component (i) during a given fishing year. Again, the estimates of ex-vessel revenue for each 2-week period were aggregated over an entire calendar year. The difference between the two sums of predicted ex-vessel revenue (annual predicted output with and without the presence of hurricanes) was interpreted as the annual economic effect of a hurricane season at the regional level. The sample economic loss was extrapolated to the entire regional fleet for an estimate of total economic damages to a regional sub-component of the GOMRF grouper sector. It is important to indicate that Models 1 and 2 were complementary in assessing the economic effects of hurricanes on commercial fish production, since we were unable to estimate the economic effect of a specific storm on nearby locales to the impact area due to an inadequate degree of spatial resolution associated with the logbook data.

4 Results and discussion

4.1 Model performance and characteristics of the technology

Tables 4 and 5 present the ML parameter estimates of the SPF specified by Models 1 and 2, respectively. Model 1 was estimated using its full specification, as well as a restricted version omitting seasonal variability. Since all three estimated models displayed coefficients with comparable patterns, magnitudes, and statistical significance, the following discussion of results relates to the full specification of Model 1. As shown at the bottom of Table 4, the value for λ, the ratio of the standard error of u to that of v, was statistically different from zero at $\alpha = 0.01$. The rejection of the null hypothesis, H_o: $\lambda = 0$, implies the existence of a stochastic frontier function (Schmidt and Lin 1984; Solís et al. 2007).

The data were normalized by their GM prior to estimation; thus, first-order coefficients of the empirical SPF were interpreted as partial production elasticities at the GM. Partial production elasticities measure the proportional increase in output attributed to a 1 % increase in a particular input. As expected, all partial production elasticities were positive and statistically significant, indicating that the studied sample operated in the appropriate range of production and that the condition of monotonicity was satisfied. That is, an increase in an input increases output. The partial elasticities were 0.64 for *Expenses*, 0.21 for *Crew*, and 0.13 for *Days*. In other words, all other things being equal, a 10 % increase in variable expenditures (other than labor) increased, on average, the bi-weekly ex-vessel revenue for the grouper sector by 6.4 %. The average crew size and number of days fished for the grouper sector were approximately 2.5 and 4.8, respectively (Table 1). Thus, all other things being equal, employing an extra crew member (i.e., increased *Crew* by 40 %) or extending a trip by an extra day (i.e., increased *Days* by about 20 %) increased, on average, bi-weekly ex-vessel revenue by 8.4 and 2.6 %, respectively.

The scale elasticity, which measures the proportional increase in output for a 1 % increase in all inputs, was 0.98 suggesting the presence of constant returns to scale (CRS). This result was corroborated using a likelihood ratio test ($\chi^2_{[DF=1]} = 1.37$). CRS implies that the level of productivity depends on improvements in technology and efficiency, and not necessarily on the scale of the regional industry. Similar results are presented by Kompas and Che (2005) and Alvarez and Schmidt (2006) for commercial fisheries in southeast Australia and northern Spain, respectively. However, Squires and Kirkley (1999) found the presence of variable returns to scale for the US Pacific Coast trawl fishery; whereas Sharma and Leung (1999) report increasing returns to scale for the Hawaii-based longline fishery.

The estimated production frontier included variables to control for non-weather-related factors affecting fish production; some of which displayed some interesting results. For instance, the average length of vessels (L) across regional sub-components of the grouper

Table 4 Parameter estimates of the stochastic production frontier for Model 1: individual hurricane effects on the grouper fleet of the GOMRF fishery

	With seasonal effect		Without seasonal effect	
	Coefficient	SE	Coefficient	SE
Constant	10.754***	0.611	10.498***	0.615
Crew	0.205***	0.048	0.202***	0.049
Days	0.126**	0.054	0.133**	0.055
Expenses	0.637***	0.053	0.632***	0.053
$Crew^2$	−0.174	0.115	−0.169	0.117
$Days^2$	0.087	0.124	0.123	0.127
$Expenses^2$	−0.643***	0.089	−0.618***	0.092
Crew × days away	−0.347***	0.092	−0.337***	0.094
Crew × expenses	0.509***	0.094	0.491***	0.095
Days × expenses	0.206**	0.094	0.176*	0.097
Length	0.308*	0.157	0.193	0.158
Cindy & Dennis	−0.607***	0.160	−0.677***	0.161
Katrina	−0.357**	0.153	−0.437***	0.155
Rita	−0.257*	0.150	−0.125	0.150
Wilma	−0.474***	0.155	−0.364**	0.157
Humberto	0.096	0.166	−0.032	0.165
Dolly	−0.024	0.202	−0.143	0.204
Gustav	−0.302*	0.159	−0.410**	0.161
Ike	0.212	0.191	0.094	0.193
Ida	−0.391**	0.189	−0.480**	0.195
Tilefish closure	−0.169***	0.059	−0.120**	0.055
Grouper closure	0.016	0.063	−0.016	0.051
FL closure	−0.081	0.070	−0.109	0.071
Quarter 1	0.108	0.077	–	
Quarter 2	0.099	0.061	–	
Quarter 4	0.181***	0.046	–	
LA	0.233***	0.061	0.213***	0.061
ALMS	0.156**	0.069	0.151**	0.071
ECFL	0.065	0.052	0.057	0.053
BBFL	−0.262***	0.063	−0.267***	0.064
WCFL	0.184***	0.056	0.195***	0.058
Trend	0.038***	0.014	0.040***	0.014
σ_u	0.462***	0.030	0.459***	0.030
σ_v	0.194***	0.020	0.204***	0.020
$\lambda = \sigma_{u}/\sigma_v$	2.382***	0.044	2.251***	0.046
Log-Likelihood	−357.776		−365.278	

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

Note: The dependent variable is the bi-weekly ex-vessel revenue of total catch landed, measured in US dollars

Table 5 Parameter estimates of the stochastic production frontier for Model 2: effect of hurricane seasons from 2005 to 2009 on Gulf sub-regions dependent on commercial grouper fishing

Variable	Coefficient	SE	Variable	Coefficient	SE
Constant	10.469***	0.614	2008 LA	–	–
Crew	0.223***	0.049	2008 ALMS	−0.301	0.220
Days	0.115**	0.054	2008 ECFL	−0.317*	0.174
Expenses	0.627***	0.053	2008 BBFL	0.285	0.229
$Crew^2$	−0.224**	0.113	2008 WCFL	−0.057	0.180
$Days^2$	0.154	0.126	2008 SWFL	−0.872***	0.231
$Expenses^2$	−0.585***	0.089	2009 LA	–	–
Crew × days away	−0.297***	0.092	2009 ALMS	–	–
Crew × expenses	0.494***	0.093	2009 ECFL	−0.363	0.286
Days × expenses	0.132	0.094	2009 BBFL	−0.282	0.290
Length	0.082	0.158	2009 WCFL	−0.647**	0.289
2005 LA	−0.300*	0.153	2009 SWFL	–	–
2005 ALMS	−0.259	0.243	Tilefish closure	−0.119**	0.053
2005 ECFL	−0.302*	0.166	Grouper closure	−0.019	0.050
2005 BBFL	−0.882***	0.218	FL closure	−0.119*	0.070
2005 WCFL	−0.263	0.176	LA	0.199***	0.063
2005 SWFL	−0.324*	0.167	ALMS	0.137*	0.073
2007 LA	−0.474	0.292	ECFL	0.038	0.054
2007 ALMS	0.027	0.294	BBFL	−0.271***	0.064
2007 ECFL	−0.301	0.286	WCFL	0.176***	0.057
2007 BBFL	0.404	0.287	Trend	0.042***	0.014
2007 WCFL	−0.466	0.286			
2007 SWFL	−0.244	0.289			
σ_u	0.458***	0.019			
σ_v	0.191***	0.029			
$\lambda = \sigma_u/\sigma_v$	2.392***	0.044			
Log-likelihood	−351.985				

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

Note: The dependent variable is the bi-weekly ex-vessel revenue of total catch landed, measured in US dollars

sector showed a positive and statistically significant effect on revenue, suggesting that larger vessels were more productive than smaller ones. This result agrees with Herrero and Pascoe (2003). These authors explain that larger vessels have larger holds, so are able to maximize time fished for a given trip length which significantly improves their productivity.

Four of the five parameter estimates associated with the regional dummy variable (*Z*) were statistically significant, suggesting that the regions studied displayed major differences in productivity. Regions LA, ALMS, ECFL, and WCFL displayed positive coefficients indicating a higher level of productivity in those regions than in SWFL (the omitted level of the regional dummy variable) given their level of inputs used. Although trips landing catch at WCFL ports reported the highest aggregate harvests among the six regions, operations landing catch in LA showed the highest level of productivity; whereas operators landing catch in the BBFL region were the least productive. The time trend (*T*), which captured a simple technological process, was positive and statistically significant suggesting the presence of positive technical changes in the sample during the studied period. Advances in fish-finding technology during this time period explained part of this phenomenon. This result agreed with the findings presented in Kirkley et al. (2007).

Regulatory restrictions (*C*) displayed mixed results. On the one hand, tilefish closures showed a negative and statistically significant effect on total revenue in all three estimated models. The coefficient for the emergency closure of FL waters was negative in all three models but significant only in Model 2 (Table 5). However, grouper closures had no significant impact on productivity in the studied area. Explanations may relate to the targeting behavior of captains, year-round ability to land gag and red grouper (except in 2005 and during spawning closures), and output substitutability of DWG and tilefishes with SWG and other reef fish. Mixed results on the impact of closures on fish production are also reported by Cai et al. (2005) for Hawaii's longline fishing industry.

The estimated coefficients of the seasonal dummy variable (*Q*) suggested that productivity levels in late winter and early spring were significantly higher than those in the rest of the year. Alvarez and Schmidt (2006) also report similar differences in seasonal harvests. Additionally, all the coefficients associated with *Q* were positive, and Quarter 4 was statistically significant, which indicated that the omitted level of the seasonal dummy variable (Quarter 3) was associated with the lowest level of productivity. Quarter 3 included the most active part of the Atlantic hurricane season in every year.

4.2 Fleet-wide and regional economic analyses

We used the results from the empirical estimation of the alternative specifications of the SPF to measure the economic effects associated with various hurricanes affecting the grouper sector of the GOMRF fishery from 2005 to 2009. First, we analyzed the fleet-wide, initial (bi-weekly) economic effect due to losses in production associated with specific hurricanes using the results from the restricted specification of Model 1. The null hypothesis that all parameters associated with the hurricane dummy variable (*H*) were simultaneously zero was rejected using a likelihood ratio test ($\chi^2_{[DF=9]} = 39.80$). In addition, eight of the nine hurricane variables displayed negative coefficients, and five of those were statistically significant. This outcome is consistent with previous research describing the negative effect of hurricanes on US commercial fishing (Buck 2005; Burgess et al. 2007; Caffey et al. 2006; NMFS 2007).

The estimated ME of each hurricane that affected the Gulf grouper sector during 2005 to 2009 is presented in Table 6. The ME measures the percentage change in the total revenue of bi-weekly production due to the impact of a hurricane. This table also presents estimated foregone revenue for the studied sample and an extrapolation for the whole population. Table 6 shows that Hurricanes Cindy and Dennis had the largest negative effect on production. These two storms struck the US during the same time period. The combined ME of these two hurricanes was −0.49. That is, in early July of 2005, these two hurricanes reduced the bi-weekly revenue of the entire Gulf grouper sector by an estimated 49 % compared to historical production levels. In monetary terms, this reduction in production equals a loss of revenue close to $82,500 for the sample and $206,000 for the population during the 2-week period affected by those hurricanes. For the sampled fleet, the individual storm that caused the highest initial economic damage, with respect to disruptions in commercial production, as estimated by the SPF model was Ida ($74,907),

Table 6 Initial fleet-wide economic damages to the grouper sector of the GOMRF fishery due to Atlantic hurricanes from 2005 to 2009

Hurricane	Marginal effect	Estimated revenue loss for sample (US $2009)	Extrapolated revenue loss for the population (US $2009)
Cindy & Dennis	−0.49	82,478	206,195
Katrina	−0.35	59,383	148,458
Rita	−0.12	16,376	40,940
Wilma	−0.31	42,394	105,985
Humberto	−0.03	5,720	14,300
Dolly	−0.13	25,151	62,878
Gustav	−0.34	63,467	158,668
Ike	0.10	–	–
Ida	−0.38	74,907	187,268

followed by Gustav ($63,467), Katrina ($59,383), and Wilma ($42,394). In total, we estimated that the Gulf grouper industry was saddled with immediate revenue losses of at least $927,000 from 2005 to 2009. Note that these losses were attributed only to disruptions in commercial harvests during the 2-week period associated with the impending landfall and immediate aftermath of Gulf hurricanes. These immediate-term losses are essential for the short-term operation of the fleet, especially for those vessels operating at the margin.

We used the ML parameter estimates associated with Model 2 in Table 5 to evaluate the effect of a hurricane season on regions along the coastline of the US Gulf of Mexico. Model 2 included a dummy variable (N) that controls for the effects of a hurricane season on production at a regional level. The parameter estimates for this dummy variable displayed interesting patterns. For instance, the 2005 hurricane season, which was the busiest in our sample, displayed negative coefficients for all regions, and four out of the six estimates were statistically significant. The region that experienced the largest economic effect was BBFL, followed by LA, SWFL, and ECFL. During 2005, three hurricanes landed in Louisiana, one in northeast FL, and one in southwest FL. Furthermore, these hurricanes exerted strong surge impacts along the FL coast, creating large shelf-waves especially in the BBFL region (Dukhovskoy and Morey 2011).

The 2006 and 2007 hurricane seasons showed no significant effects on any regions in the studied area. In 2006, the US Gulf of Mexico was not affected by any major tropical storms, while the 2007 season had only one hurricane, Humberto, which was a small storm affecting the western side of TX. During 2008, two hurricanes landed in TX (Dolly and Ike) and one in Louisiana (Gustav). Hurricanes Dolly and Gustav exhibited tracks affecting the FL Keys, and southwest FL which explains the negative and statistically significant impact found for the SWFL region during 2008. Hurricane Gustav landed in Louisiana as a category 2 hurricane. Several hurricane warnings were issued to avoid major catastrophes in the area. These warnings may have discouraged fishermen from landing in the threatened regions. Thus, no observations were reported for the LA region during the time period; and consequently, this region was dropped in the estimation of the SPF for the 2008 hurricane season. However, negative impacts were found for the ALMS and ECFL regions with the coefficient for the latter statistically significant. Hurricane Ike also likely contributed to these regional impacts; however, like Gustav, due to inactivity during the biweek associated with its Galveston, TX landfall, no observations were reported for the TX

Table 7 Initial economic damages due to the effect of a hurricane season at the regional level[a]

Hurricane season	Gulf sub-region	Marginal effect	Estimated revenue loss for the sample (US $2009)	Extrapolated revenue loss for the population (US $2009)
2005	LA	−0.30	35,582	88,955
	ECFL	−0.27	15,832	39,580
	BBFL	−0.59	11,893	29,733
	SWFL	−0.28	16,662	41,655
2008	ECFL	−0.27	27,147	67,868
	SWFL	−0.58	15,438	38,595
2009	WCFL	−0.48	23,569	58,923

[a] The economic effect was computed for those regions with statistically significant impacts based on the estimates in Table 5

region. The lack of a reasonable amount of observations related to hurricanes Gustav and Ike reinforce the notion that our estimates of economic displacement to industry calculated from the MEs in Table 6 were on the low side as commercial grouper trips totally ceased in LA and TX. The loss of revenues associated with these shutdowns was not estimable with the SPF model but could be measured with the revenue comparison approach. This should alert managers early in the federal relief process that indeed a potentially serious situation has happened with the commercial fishing fleet in that area. Thus, the production approach may serve as an early warning system for future fishery disaster claims.

The 2009 season presented an interesting pattern due to the inherent attributes of Hurricane Ida, the only storm affecting the area that year. Ida entered the Gulf of Mexico as a hurricane where strong shear removed the convection from the low-level center, and the hurricane weakened to a tropical storm, as shown in Fig. 2. However, Ida again reached hurricane strength when approaching the mouth of the Mississippi River then became a tropical storm a few hours before it moved inland along the Alabama coast. Hurricane warnings were issued for the Louisiana, Mississippi, and Alabama coasts. As a consequence, no observations were reported for the LA and ALMS regions. The surge impact along the FL coast was depicted by the negative and statistically significant coefficients found in regions BBFL and WCFL after accounting for the closure of the west Florida Shelf to bottom longline gear. Region ECFL also displayed a negative but not significant effect during the 2009 hurricane season.

Table 7 presents the ME of each hurricane season on those regions with statistically significant impacts on production, based on the estimates presented in Table 5. This table also exhibits the initial economic effects, in monetary terms, for our studied sample, as well as an extrapolation to the whole population using weighted averages based on trip efforts. The region with the largest ME was BBFL in 2005 (−0.59), followed by SWFL in 2008 (−0.58) and WCFL in 2009 (−0.48). From a monetary point of view, the regions with the biggest extrapolated losses in revenue due to production disruptions were LA in 2005 ($88,955), ECFL in 2008 ($67,868), and WCFL in 2009 ($58,923).

For instance, the initial economic displacement to LA operators from three hurricanes in 2005 was estimated to be $88,955 or $1,482 per boat on average. Furthermore, indirect impacts, likely from storm surge and precautionary practices in response to pre-storm warnings, were identified in regions outside of Hurricane Ida's path in 2009. After accounting for an emergency closure in FL waters, the WCFL region was estimated to have lost nearly $60,000 in the 2-week production period when Ida formed. This represented a nearly 50 % loss in historical production. The ECFL and SWFL regions also experienced extensive losses in productivity of nearly 60 % in 2005 and 2008, respectively. These numbers raise an interesting point. Grouper fishers seem to be well aware of the possible impacts of inclement summertime weather in addition to high temperatures in the Gulf of Mexico regardless if a hurricane is approaching. As the empirical results suggested, Quarter 3 traditionally has been a period of low productivity for this fishery. Therefore, changes in productivity due to early summer storms were likely to have less of a dramatic effect on revenues as harvest levels were relatively low during these months. Storms forming late in the hurricane season potentially could have a much greater effect on grouper production as harvest levels were much higher especially off the coast of west FL.

5 Summary and conclusions

This paper used SPF to measure the initial economic effects imposed on the fishing industry when production is disrupted due to a hurricane. The model measures fleet-wide and regional economic displacement directly associated with changes in the productivity of the fleet. The empirical analysis was applied to a case study involving the grouper sector of the GOMRF fishery. A translog functional form was specified that related bi-weekly ex-vessel revenue to major production inputs as well as controlled for variables that affect industrial production. The empirical model satisfied necessary conditions of a theoretical production function; thus, the empirical application was able to measure changes in production due to hurricanes while controlling for other factors affecting production such as regulations and seasonality. Results describing the technological structure of the studied industry were corroborated with previous research and historical observations suggesting that the model provided useful information about the underlying operational structure of the fleet. Lastly, differences in productivity due to average vessel length, geography, seasonality, and regulations were identified.

The initial economic effect of a hurricane was determined by identifying changes in productivity within the bi-week of its landfall and the subsequent foregone ex-vessel revenue. This connection was established by calculating the ME of a hurricane from the ML parameter estimates of the hurricane-specific dummy variables in Model 1 and hurricane season dummy variables in Model 2. Economic effects, in monetary terms, were calculated by comparing predicted output with and without the presence of hurricanes for each model.

The SPF model isolated the economic effects on productivity due to individual hurricanes, resulting in an estimate of foregone revenue. Although we measured economic effects associated with the initial 2-week period of the storm, this result was significant as the true economic effect of a hurricane on commercial production can be confounded by a number of bioeconomic, environmental, and regulatory factors. The ability of the model to measure the economic effect on regional fishing communities was also a significant result. Moreover, the model identified surge and other ancillary effects that altered productivity in areas far away from the storm's landfall.

Although the empirical results of our analysis were encouraging, some caveats are necessary. As employed in this study, the SPF model does not incorporate zero harvest levels which forced a constricted definition of the fleet. Additionally, in local areas that were extremely impacted by a hurricane, data points did not exist precluding an economic effects analysis. Therefore, the measures of economic displacement produced by the SPF model were interpreted as lower bound estimates of the true economic effect on commercial fishing operations caused by the storm.

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References

Aigner D, Lovell K, Schmidt P (1977) Formulation and estimation of stochastic frontier production function models. J Econom 6:21–37

Alvarez A, Schmidt P (2006) Is skill more important than luck in explaining fish catches? J Prod Anal 26:15–25

Box G, Tiao G (1975) Intervention analysis with applications to economic and environmental problems. J Amer Statist As 70:70–79

Bravo-Ureta B, Solís D, Moreira V, Maripani J, Thiam A, Rivas T (2007) Technical efficiency in farming: a meta-regression analysis. J Prod Anal 27:57–72

Buck E (2005) Hurricanes Katrina and Rita: fishing and aquaculture industries—damage and recovery. Congressional Research Service, Report for Congress No. RL34209

Burgess C, Bianchi A, Murauskas J, Crosson S (2007) Impacts of hurricanes on North Carolina fisheries. North Carolina Department of Environment and Natural Resources, Division of Marine Fisheries. p 233

Caffey R, Kazmierczak R, Diop H, Keithly W (2006) Estimating the economic damage of Hurricanes Katrina and Rita on commercial and recreational fishing industries. Paper presented at the American Agricultural Economics Association Annual Meeting, Portland, Oregon, July 29-August 4th, 2007

Cai J, Leung P, Pan M, Pooley S (2005) Economic linkage impacts of Hawaii's longline fishing regulations. Fish Res 74:232–242

Conner W, Day J, Baumann R, Randall J (1989) Influence of hurricanes on coastal ecosystems along the northern Gulf of Mexico. Wetlands Ecol Manage 1:45–56

Dolloff C, Flebbe P, Owen M (1994) Fish habitat and fish populations in a southern Appalachian watershed before and after Hurricane Hugo. Trans Am Fish Soc 123:668–678

Dukhovskoy D, Morey S (2011) Simulation of the Hurricane Dennis storm surge and considerations for vertical resolution. Nat Hazards 58:511–540

Greene W (2008) The econometric approach to efficiency analysis. In: Fried H, Knox Lovell C, Schmidt S (eds) The measurement of productive efficiency and productivity growth. Oxford University Press, Oxford, pp 100–103

Herrero I, Pascoe S (2003) Value versus volume in the catch of the Spanish South-Atlantic trawl fishery. J Agric Econ 54:325–341

Kirkley J, Walden J, Ward J (2007) The status of USA's commercial fisheries and management and crystal-balling the future. Int J Global Environ Issues 7:119–136

Kompas T, Che T (2005) Efficiency gains and cost reductions from individual transferable quotas: a stochastic cost frontier for the Australian South East fishery. J Prod Anal 23:285–307

Kumbhakar S, Lovell K (2000) Stochastic frontier analysis. Cambridge University Press, Cambridge, pp 72–93

Nidhiprabha B (2007) Adjustment and recovery in Thailand two years after the tsunami. ADBI Discussion Paper 72. Tokyo: Asian Development Bank Institute

NMFS (National Marine Fisheries Service) (2007) Report to congress on the impact of hurricanes Katrina, Rita, and Wilma on commercial and recreational fishery habitat of Alabama, Florida, Louisiana, Mississippi, and Texas. Silver Spring, Maryland

Schmidt P, Lin T (1984) Simple tests of alternative specifications in stochastic frontier models. J Econom 24:349–361

Sharma KR, Leung P (1999) Technical efficiency of the longline fishery in Hawaii: an application of a stochastic production frontier. Marine Res Econ 13:259–274

Solís D, Letson D (2013) Assessing the value of climate information and forecasts for the agricultural sector in the Southeastern United States: multi-output stochastic frontier approach. Reg Environ Change. doi: 10.1007/s10113-012-0354-x

Solís D, Bravo-Ureta B, Quiroga R (2007) Soil conservation and technical efficiency among hillside farmers in Central America: a switching regression model. Aust J Agr Resour Econ 51:491–510

Squires D, Kirkley J (1999) Skipper skill and panel data in fishing industries. Can J Fish Aquat Sci 56:2011–2018