Economic and Physical Measures of Efficiency: the Case of the Gulf of Mexico Grouper Fishery

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## Background

The Gulf of Mexico Reef Fish Fishery Management Plan (RFMP) was one of the first FMP's submitted by the Gulf Council. Reef fish identified and managed under the original plan included 14 species of snappers (*Lutianidae Family*), 15 species of groupers (*Serranidae Family*) and three species of sea basses. Subsequent amendments to the Plan added five species of tilefishs (*Branchiostegidae Family*), two species of jacks (*Carangidae Family*), white grunt (*Haemulon plumieri*), red porgy (*Pagrus pargus*), and gray triggerfish (*Balistes capriscus*). The goal identified in the original Plan was "[t]o manage the reef fish fishery of the United States waters of the Gulf of Mexico to attain the greatest overall benefit to the Nation with particular reference to food production and recreational opportunities on the basis of maximum sustainable yield as modified by relevant economic, social, and ecological factors (p.2)." Pursuant to this goal, one of the primary objectives set forth in the plan was to rebuild declining reef fish stocks wherever they occurs in the fishery. While encompassing a large number of species, because of its heavily overfished status, the majority of the Council's reef fish management activities have historically been red snapper oriented. More recently, management attention has been given to the grouper complexes. This attention reflects increasing conflicts among different segments of the industry as well as concern regarding the status of some of the individual species.

For the purposes of management, grouper stocks are divided into two groups. The first group, referred to as the shallow-water grouper, is managed in aggregate with an overall quota of 8.8 million pounds of which 5.31 million pounds are allocated to red grouper. The second group, the deep-water grouper, is also managed in aggregate with an overall quota of 1.2 million pounds. Three grouper species – red, gag, and black- comprise the majority of commercial shallow-water grouper landings. Longlines and vertical lines represent the primary gear types used to commercially harvest the shallow-water. While most vessels will fish with only one gear or the other during the course of a year, a limited amount of switching behavior is reported. (Poffenberger, John. National Marine Fisheries Service, personal communication).

Based on logbook data, 915 vessels reported grouper activities in 2004; approximately 164 of these vessels reported use of longlines. The longline vessels reported 1671 trips in 2004, typically lasting up to 9 days in length. The vertical line vessels, by comparison, generally make trips lasting only a couple of days in length. While the vast majority of the vertical line vessels harvested about 394 pounds of grouper per trip, approximately the longline vessels reported landings which suggested more than 3500 pounds of grouper per trip, on average. In comparison, in 1993, about 1068 vessels reported grouper activities. Among those, 183 used longlines as fishing gears while 869 used vertical lines. The vertical liners landed about 360 pounds of groupers per trip while longliners harvested about 3300 pounds of grouper per trip. It is worthwhile noticing that landing of the longliner in 1993 are about 400 pounds per trip below the realized landings of 2004.

The majority of red grouper is harvested with longlines (approximately 80%) while the majority of black grouper is harvested with vertical lines. While the reason for this breakdown has not been established, industry sources suggest that gag and black grouper tend to aggregate and, hence are susceptible to vertical lines (referred in this research as vertical line). Red grouper, by comparison, does not tend to aggregate (except during spawning) and, hence, is not susceptible to vertical line gear; however, longline gear is ideally suited for harvesting this species. Overall, the proportion of red grouper taken by the longline sector has increased substantially since the mid-1980s.[1]

The National Marine Fisheries Service has recently declared red grouper as overfished. Furthermore, gag grouper, though not overfished, are approaching an overfished condition. In response the Gulf of Mexico Fishery Management Council (GMFMC) has "elected to revisit its overall strategy for managing groupers (Draft Amendment 18, no page number)." To this end, the Council, through Draft Amendment 18 to the RFMP, is considering a number of different options which would allow rebuilding of the stock. Those options vary significantly in scope and include such measures as closed seasons/areas, individual species quotas, and limited entry. Additionally, catch per unit of effort for the grouper fishermen has risen in recent years and fishery planners suggest investigating whether this increase is related to stock rebuilding[1] measures implemented by the National Marine Fisheries Service or to an increase in the efficiency of the fleet due to capital stuffing (GPS and fish finder devices that the boats are equipped with). Additionally, it has been argued (Kirkley et al. 2003; Pascoe and Coglan, 2002) in the fisheries economics literature that variation in fishing powers among vessels could be attributed to three main factors: unmeasurable differences in on-boat technology, variation in skipper skills and pure luck. While variation in skipper skills was found to be the strongest determinant of fishing power (Crutchfield and Gates, 1985), some authors have argued that most unexplained portions of fishing powers are attributable to pure "luck" (Hilborn and Ledbetter, 1985). Highest amount of luck in a fishery is commonly associated with difficulties to standardize effort using fishing powers (Pascoe and Coglan, 2002). To circumvent the problem

[1] In general, there are relatively few regulations regarding the harvest of grouper (other than size restrictions). One that should be mentioned though is the fact that longline vessels must operate outside the twenty fathom range. Relatively little red grouper is harvested outside the fifty fathom range.

[1] For example, Amendment 1 to the Reef Fish Fishery Management Plan established a 10-year rebuilding plan for the red grouper with quotas and recreational bag limits. The 2002 stock assessment indicates that grouper stocks are on the rise.

of luck in fishery, one can estimate the fishing efficiency of every boat using a Stochastic Frontier Production (SFP). With this approach, the luck component is captured by the stochastic component of the SFP and measurable and unmeasurable components of the fishing power will be separated out using statistical techniques (Pascoe and Coglan, 2002). This paper will evaluate the technical efficiency of the grouper fishing fleet using the Stochastic Frontier Production frontier method.

Data and Methods

The use of a stochastic production function to estimate an efficiency frontier for the fleet (and, indeed, for each individual vessel) can be accomplished in a straightforward manner given information on the inputs used and outputs generated by each vessel in the fleet. The stochastic production frontier can be defined as (Aigner et al. (1977), Meeusen and Van den Broeck (1977), Coelli et all (2005))

$$\begin{aligned} Log(Q_{it}) = {} & \beta_0 + \beta_1 * \ln(Effort) + \beta_2 * \ln(Crew) + \beta_3 * \ln(Hardbot) + \beta_4 * \ln(Effort)^2 + \\ & \beta_5 * \ln(Crew)^2 + \beta_6 * \ln(Hardbot)^2 + \beta_7 * \ln(Effort) * \ln(Crew) + \\ & \beta_8 * \ln(Effort) * \ln(Hardbot) + \beta_9 * \ln(Crew) * \ln(Hardbot) + \beta_{10} * D96 + \\ & \beta_{11} * D97 + \beta_{12} * D98 + \beta_{13} * D99 + \beta_{14} * D00 + \beta_{15} * D01 + \beta_{16} * D02 + \\ & \beta_{17} * D03 + \beta_{18} T + (V_{it} - U_{it}) \end{aligned} \qquad (1)$$

where, $Q_{it}$ is the annual harvest of fish per vessel; *Effort* is the a composite index of soak time, gear length and number of hooks per gear for the vertical liner and soak time and number of hooks per line for the long liners; *Crew* represents the average crew size per vessel per year; *Hardbot* is an annual percentage of area hard bottom visited by a vessel and weighted by associated time spent fishing on that location; *D96* through *D03* are annual binary variables used as a proxies for weather shocks and stock abundance; and *T* is a time trend used as a proxy for technological change. The split error term, $\left(V_{j,t} - U_{j,t}\right)$ is composed of measurement and approximations errors ($V_i$ ) and a measure of technical inefficiency ($U_i$ ). In a condensed form, the above translog function could be rewritten as

$$\ln\left(Q_{it}\right) = x'_{i,t} = \beta + \left(V_{it} - U_{it}\right) \qquad (2)$$

The stochastic production frontier approach has most frequently appeared in the literature as a way of predicting technical efficiency defined as the ratio of the observed output to the corresponding frontier output

$$TE_i = \frac{Q_i}{\exp\left(x'_i\beta + v_i\right)} = \frac{\exp\left(x'_i\beta + v_i - u_i\right)}{\exp\left(x'_i\beta + v_i\right)} = \exp\left(-u_i\right) \qquad (3)$$

where $0<TE_i<1$ and the time subscript is suppressed for clarity. With this formulation, the efficiency effects are assumed to be independently and identically distributed as truncation of normal distribution with constant variance, but with means that are linearly dependent on observable variables. Efficiency for a specific vessel then becomes

$$E\left[e^{(-u_{jt})}\middle|\varepsilon_{j,t}\right]=\frac{1-\phi(\sigma_A+\gamma\varepsilon_{j,t}/\sigma_A)}{1-\phi\left(\gamma\varepsilon_{j,t}/\sigma_A\right)}xe^{\left(\gamma\varepsilon_{j,t}+\sigma^2/2\right)} \qquad (4)$$

where $\sigma_A=\sqrt{\gamma(1-\gamma)\sigma_s^2}$ , $\sigma_s^2\equiv\sigma_u^2+\sigma_v^2$ , $\gamma\equiv\sigma_u^2/\sigma_s^2$ , and $\phi(.)$ is the density function of a standard normal random variable (Battese and Coelli (1988), Pascoe and Coglan (2002)). When $\gamma=0$ and $\sigma_u^2=0$ , the vessel is perfectly technically efficient and thus lies on the frontier. This suggests a simple test for inefficiency by examining, among other things, the null hypothesis that $\gamma=0$ versus the alternative hypothesis that $\gamma>0$ . This can be accomplished with a simple z statistic given that the unconstrained maximum likelihood estimators (which should be the method of choice in this model) are asymptotically normally distributed (Coelli et al. 2005). If $\gamma$ is between 0 and 1, both technical inefficiency and random component variation combined explain deviations from the frontier (Battese and Cora, 1977).

## Data

The reef fish logbook data were made available by the National Marine Fisheries Service (NMFS) and they included information on fishing trips, area fished, fishing effort, and landings per species, prices and vessel characteristics. The database identifies 21 fishing areas in the Gulf of Mexico, contiguous along the coast, where grouper fishermen operate. Nine years of data covering 1996 through 2004 were used in the analysis. The data were aggregated annually on a vessel basis. Two scenarios were estimated; a) vessels with at least 20 percent of annual landed poundage composed of grouper complex and b) vessels with grouper landing share at least totaling 50 percent. The rational for running these scenarios was to investigate the degree to which a specialization in the grouper complex fishing is affecting efficiency. The data were classified into vertical liner and longliner. For each fishing technology, we used the Battese and Coelli (1995) model for firm specific technical inefficiency to identify fixed and variable factors that influence technical efficiency.

The data[2] required for the analysis included measures of outputs and inputs, resource abundance, and a set of fixed factors. Following Kirkley et al. (2003), the outputs were measured in pounds. The input variables used were effort, crew size. The fixed factors are stock abundance (proxied by binary variables), fish habitat. Although these inputs are not typical of those considered in analysis of other industries (e.g. fuel costs, capital services, etc.), they are consistent with the way fisheries managers and scientists consider the inputs to harvesting (Kirkley et al. 2003, Felthoven and Paul 2004). For example, many of the inputs for fisheries are regulated, such as days at sea or effort, which represent capital, energy, materials and labor (Kirkley et al. 2003).

[2] The data cover year 1996 through 2004

A functional relationship between reef fish habitat utilization and grouper life history stage is provided in Table 41 of The Gulf of Mexico Fisheries Management Council Draft of the Amendment 27 to the Reef Fish Fishery Management Plan[3]. Measures of hard water bottoms were derived from the Marine Resource Assessment Group (MRAG[4]) habitat data and used in the estimation because this physical feature is considered an essential habitat type for most grouper species. In order to incorporate it into our estimations, we created a statistical grid map similar to the one included in the reef fish vessel logbooks and overlaid it on the MRAG map, thereby generating the amount of bottom type within each statistical grid. That amount was then linked to vessels that fished in the specific grid.

The effort data used in the analysis came from the logbook vessel record and represented the estimated time that gear was fishing during an entire trip. In general, fishing efforts should be measured in units that are proportional to fishing mortality (Gulland, 1983). When dealing with demersal fisheries, however, effort can be measured as catch per unit allocated during fishing time, with all inputs allocated during search time ignored (Weninger 2001). For the demersal grouper fisheries, therefore, the most appropriate measure of effort should be the time the gear is in the water and capable of harvesting. Additionally, soak time will address the issue of capital underutilization as in Pascoe and Coglan (2003). The non separation between capital underutilization and technical inefficiency could lead to underutilization of resources to be interpreted as inefficiency (Harris, 1993). We constructed an effort variable that is a product of soak time, gear length and number of hooks per gear for the vertical liners. For the longliners, the effort variable was measured as amount of soak time multiplied by number of hooks per gear.

Stock abundance, which is generally subject to a high degree of variability over years, seasons, areas and gears (Pascoe and Coglan, 2002), will affect catch composition per vessel. Accounting for this variability in a disaggregate way, however, not only requires highly detailed data but will also result in a significant loss of statistical degrees of freedom, perhaps calling into question the robustness of the estimations. For example, in the case of the grouper fisheries there were potentially 9 years of data for each of 21 statistical areas. Since we don't have detailed stock variables to account for stock, we use yearly binary variables as a proxy for stock abundance.

## Results

Two separates models were estimated; one for the longliners and one for the vertical liners. Initial tests using White (1980) statistics revealed that heteroscedasticity was a problem for both stochastic production frontier models[5]. White statistics for long liners is 196 (associated Chi Square pvalue is 0.001) and for vertical liner is 239 (associated Chi Square probability is 0.001). Since heteroscedasticity was evident in both models, the appropriate corrections were made. The adjusted R-square was 0.96 (Table 1) for the vertical liners and 0.97 for the long-liners (Table 2).

[3] Gulf of Mexico Fisheries Management Council, 2203 North Lois Avenue, Suite 1100. Tampa, Florida 33607. Publication Award No. NA05NMF4410003-06

[4] Gulf of Mexico Essential Fish Habitat Geographic Information System Project. GIS solutions, Inc, 111 2nd Ave NE. St. Petersburg, Fl 33701.

[5] Although we corrected for heteroscedasticity in the stochastic production model, no attempt was made at checking and correcting for this problem in the technical inefficiency models.

The longliner fleet[6] is found to be responsive to crew change as well as the effort weighted amount of hard bottom percentage covered within a year. A one-percent increase in crew size is associated with a 0.90 percent (Table 3) increase in annual harvest among longline vessels. Additionally, a percent increase in percentage of hard bottom is associated with 0.08 percent increase in harvest. Binary variables for year 1996 through 2003 are highly significant and positive indicating that annual harvests per vessel in years 1996 through 2003 were higher than harvest per vessel in 2004 which is the year that was dropped from the analysis to avoid the dummy variable trap. However this result is misleading since 2004 has the lowest vessel harvest (with the exception of 1996 and 1997) in comparison to the other years. If we don't account for 2004, the harvest over the study period was trending upward. The estimated coefficient associated with the variable *T* is positive and statistically significant. It indicates that the harvests by longliners vessels have been increasing by 0.89 percent per year.

For the vertical liners, a one-percent increase in effort is associated with 0.37 percent (Table 4) increase in harvest. The binary variables are also positively associated with harvest. The variable T is positively associated with harvest and it shows that vertical line vessels have been improving their harvest at a moderate rate of 0.32 percent per year.

The technical inefficiency model was defined as follows

$$U_{it} = \alpha_0 + \alpha_1 * \log(Effort) + \alpha_2 * \log(Crew) + \alpha_3 * \log(Hardbot) + a_4 * \log(T) + \varepsilon_{it} \qquad (7)$$

where $\varepsilon_t$ is an error term which captures differences in efficiencies across vessels. We used FRONTIER 4.1 (Coelli, 1996), a program developed specifically for the estimation of stochastic frontiers. The program uses a three step procedure for estimation by first employing OLS and then using a grid search to calculate a likelihood function for $\gamma$ and updating the OLS estimates of the intercept and the variance constraining the other estimates in the OLS. After a selection of the best performing preliminary model using a likelihood ratio test, the program uses the OLS estimates as starting values to obtain the final maximum likelihood estimates.

Test of the null hypothesis that inefficiency does not exist within the fisheries suggests that inefficiency explains part of the deviations from the frontier output. For the longliners, the value of $\gamma$ is 0.99 (table 5) and is statistically different from zero, which indicates that technical inefficiency is a factor explaining differences among vessel harvests. As pointed out by Kirkley and al. (1995), while it can be surprising that technical inefficiency dominates random shocks in fisheries, fishing is by nature a "hit or miss" activity and captains could mistakenly use the least efficient combination of inputs to reach a specific level of output. Captains may also misjudge a

[6] Only one scenario was run for the long liner fleet since the grouper revenues per vessel were very high and the fleet was very specialized in the grouper fisheries. Only the vessels which grouper revenues share were above 20 percent were included in the analysis. When the revenue share is increased up to 50 percent, only a handful of vessel will be drop from the analysis which is not affecting the analysis outcome. However, this is not the case with the vertical liners.

situation when dealing with technological externalities, herd behavior, or cost adjustments between trips. An examination of all these latter issues, however, was beyond the reach of the existing data.

The model also indicates that a unit increase in effort and crew size have negative effects on technical inefficiencies. In other words, increasing soak time and number of hooks per gear with an associated increase in crew size will improve the vessel efficiency. Additionally, the time trend variable is significantly associated with inefficiency. The negative sign associated with this variable provides an indication that longliners have been technically improving their efficiency over the study period. It could be also that the number of vessel has been declining over the study period while stock abundance improved which this variable is capturing.

For the vertical liners, the value of $\gamma$ is 0.99 and is statistically significant, which is an indication that this segment of the commercial fishery (i.e., vertical line vessels) experiences random shocks as well as inefficiencies. The first case scenario encompasses only vessels with grouper shares in their total revenues above 20 percent (Table 6). Results indicated that crew size decreased technical efficiency while fishing effort and time trend affected positively technical efficiency. As the vessels become more specialized in grouper fishing (vessels with grouper contributing at least 50 percent of their total revenue), crew is utilized more efficiently (Table 7). Results also indicated that overall industry technical efficiency improved as vessels become specialized in the grouper fishing activities.

## Discussion

Technology, through capital stuffing, has helped fishermen around the world to increase their vessel technical efficiency by locating and catching fishes. The consequences are shorter fishing seasons as in the Gulf of Mexico grouper fisheries, market gluts, and mismatches between capital and resources. The question is how technology early adopters differentiate themselves from the technology followers and what kind of advantages do they have? It has been documented in the fisheries economics literature (Pascoe and Coglan, 2002; Robins and al.,1998) that capital stuffing in the forms of GPS, improved sonar systems, plotters, high power fish finders and other alike electronic devices will give a small short term advantage to the adopting boat. For example Robins and al. (1998), found a 4% improved fishing power for vessels equipped with GPS devices in comparison to those that are not. That percentage jumps to 7 if the GPS is combined with a plotter. The authors also found an associated “learning effect” that constraints growth in fishing power to 2-3% over the first three years. In the Gulf of Mexico grouper fisheries, we can assume that electronic adoption is widely spread due to its low implementation cost and that the field levels off very quickly. Therefore we suspect that crew skills, although we did not include it in our model, because of lack of data, plays a crucial role in determining differences in efficiencies across vessel and technologies.

For management considerations, it is important to identify the other factors that contribute to efficiency aside from the crew skills. As pointed out by Pascoe and Coglan (2002), some of those factors can have some adverse effects on management policies such as buy back, input controls and quotas.  Inputs controls are designed to restrict the productivity of a vessel and indirectly its efficiency. With allowable gear restrictions and trip limits and areas fished in the Gulf of Mexico grouper fisheries the question is: Are those input controls effective in terms of preventing shifts from the controlled inputs to a non controlled inputs such as technology stuffing or else? When inefficient boats coexist in a fishery with efficient vessels, there is always the risk of substituting the controlled inputs with non controlled inputs. And generally the most efficient vessels benefit from this input controls since they can readapt quickly to the regulation and the least efficient could be forced out raising the question of fairness and equity.

In 2005, the Southern Offshore Fishermen's Association submitted a buyback plan to the reef fish fishermen in the Gulf of Mexico for vote. The plan was developed by the industry to avoid commercial quota closures and stabilize the fisheries.  This program, which has been under consideration with the United States Congress, was paid by the industry and was voluntary. The danger associated with a voluntary buyback program as pointed out by Pascoe and Coglan (2002) is that the least efficient vessels are the first to exit from the industry. Therefore capacity is not reduced as much as expected. Another problem with the grouper fisheries buyback programs is associated with the voting success associated with this program.  Recall that this program was designed as a two step-process. In the first step, the program is submitted to voting to the entire industry and the votes are weighted based on the fact that vessel operators are longliners or vertical liners. If the first step fails and a favorable vote is observed for the longliners in the second step, then the longliners get their quotas and they will be allowed to a one time upgrade of their vessels in size/ horse power within 25% specified limits. This amounts to increasing the fishing pressures since the remaining vessels that are supposedly the more efficient are allowed to upgrade.

The Gulf of Mexico Fisheries Management Council preferred the Individual Fishing Quotas (IFQs) to the buyback and could implement IFQs as early as in 2008 or 2009. Under this management regime, IFQs are allocated to the most efficient vessels based on their catch history. Resource will be allocated to ensure that most efficient vessels will have the highest share in the harvest.

## Conclusions

The goal of this research was to evaluate technical efficiency of the grouper fleet using stochastic frontier production. Two separate scenarios were run for the longliner and the vertical liner vessels.  Results indicated that both segment of the commercial fisheries experience random shocks as well as technical inefficiencies.

Results also indicated that vessel efficiency was positively associated with the increased in time trend over the studied period. For the longliners, results showed that increasing crew size and fishing effort could lead to an improvement in vessel efficiency.

For the vertical liners, results show that crew size is not improving vessel efficiency for the least specialized case scenario. However, as vessels are more specialized in the grouper fishing activities, the crew size becomes a significant factor of vessel efficiency improvement. Results also show that industry vessel efficiency over the study period improves as vessels become specialized.

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Table 1 Estimated Translog Production Function for the Gulf of Mexico Grouper Vertical liners 1996-2004 (Percentage of grouper share in landings is greater than 20)

| Label | Estimate | T-value |
|---|---|---|
| Constant | 0.6628 | 0.69 |
| Effort | 1.2276 | 6.10* |
| Crew | -1.7216 | -4.58* |
| Hard bottom | 0.1033 | 1.97* |
| $Effort^2$ | -0.0478 | -3.60* |
| $Crew^2$ | 0.4776 | 3.08* |
| Hard $Bottom^2$ | 0.0208 | 4.54* |
| Effort*Crew | 0.1467 | 3.48* |
| Effort*Hard Bottom | 0.0137 | -2.81* |
| Crew* Hard Bottom | -0.0291 | -0.79 |
| D96 | 2.2473 | 5.73* |
| D97 | 1.9216 | 5.62* |
| D98 | 1.9361 | 6.48* |
| D99 | 1.5031 | 5.22* |
| D00 | 1.2876 | 6.15* |
| D01 | 1.1701 | 5.67* |
| D02 | 0.8201 | 5.90* |
| D03 | 0.2701 | 2.59* |
| T | 0.3253 | 6.00* |

Adjusted $R^2$=0.96. White heteroscedasticity test before correction is 233 (Probability of associated Chi-Square is 0.001)

Table 2 Estimated Translog Production Function for the Gulf of Mexico Grouper Long liners 1996-2004 (Percentage of grouper share in landings is greater than 20)

| Label | Estimate | T-value |
|---|---|---|
| Constant | -1.7518 | -1.21 |
| Effort | 0.3348 | 1.49 |
| Crew | 0.9274 | 1.16 |
| Hard bottom | -0.9643 | 2.48* |
| $Effort^2$ | -0.0075 | -1.04 |
| $Crew^2$ | 0.4611 | -1.82** |
| Hard $Bottom^2$ | 0.0014 | 0.26 |
| Effort*Crew | -0.0870 | -1.44 |
| Effort*Hard Bottom | -0.0631 | -2.69* |
| Crew* Hard Bottom | -0.0689 | -0.98 |
| D96 | 6.9598 | 3.08* |
| D97 | 5.9890 | 3.11* |
| D98 | 5.2778 | 3.07* |
| D99 | 4.4873 | 3.28* |
| D00 | 3.5714 | 3.18* |
| D01 | 2.7037 | 3.28* |
| D02 | 1.8753 | 2.93* |
| D03 | 1.0214 | 2.70* |
| T | 0.8918 | 3.33* |

Adjusted $R^2$=0.97. White heteroscedasticity test before correction is 196 (Probability of associated Chi-Square is 0.001)

Table 3 Estimated Elasticity with Respect to Effort, Crew Size and Percentage of Hard Bottom for the Long liners.

| Elasticity with respect to | Estimate | T-Value |
|---|---|---|
| Effort | 0.1180 | 1.12 |
| Crew size | 0.9038 | 8.02* |
| Hard bottom | 0.0787 | 1.76** |

Table 4 Estimated Elasticity with Respect to Effort, Crew Size and Percentage of Hard Bottom for the Vertical liners.

| Elasticity with respect to | Estimate | T-Value |
|---|---|---|
| Effort | 0.3719 | 12.35* |
| Crew size | -0.3664 | -1.40 |
| Hard bottom | -0.0012 | -0.04 |

Table 5 Inefficiency estimates for the Long liners

| Label | Estimate | T-Value |
|---|---|---|
| Constant | -16.274 | 13.59 * |
| Effort | -24.810 | 106.01* |
| Crew | -9.883 | -9.74* |
| Hard | 0.545 | 0.593 |
| T | -2.467 | 4.341* |
| Sigma | 2550 | 2430* |
| Gamma | 0.99 | 563000* |

Table 6 Efficiency estimates for vertical liners with 20 percent of the data trimmed. (Number of observation is 961 and number of vessels is 417)

| Label | Estimate | T-Value |
|---|---|---|
| Constant | -240.06 | -18.872 * |
| Effort | -8.516 | -9.683* |
| Crew | 21.334 | 18.482* |
| Hard | 0.604 | 1.305 |
| T | -4.338 | 5,902* |
| Sigma | 1745 | 5878 |
| Gamma | 0.99 | 789301* |

Table 7 Technical Inefficiency model for the vertical liner with 50 percent trimmed (Number of observation is 887 and number of vessels is 377)

| Label | Estimate | T-Value |
|---|---|---|
| Constant | -159.27 | -33.83* |
| Effort | -0.0729 | -0.185 |
| Crew | -32.919 | -15.239* |
| Hard | 0.0607 | 0.38 |
| T | -2.956 | -12.024* |
| Sigma | 713.42 | 295.105* |
| Gamma | 0.99 | 561137* |