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Modeling Fleet Size in the Gulf of Mexico Shrimp Fishery, 1966-1979

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Modeling Fleet Size in the Gulf of Mexico Shrimp Fishery 1966-1979[1]

Introduction

The level of fishing effort applied by fishermen to common property resources is determined by the economic and biological conditions existing in the fishery. Since effort is maintained at the level where total costs are equal to total revenue, any increase in price or biomass level or decrease in cost will result in an expansion of fishing effort until the normal economic rents are dissipated. Effort levels can be altered in the short run by adjusting the variable factors of production such as crew size, days fished or trips, Long run changes in effort can be made by adjusting the fixed factors of production such as vessel length, hull material, or engine horsepower. Vessel entry and exit behavior and changes in the structure and size of the Gulf of Mexico shrimp fishing fleet are caused by these long run adjustments in fishing effort. The fleet size model developed here is designed to determine if existing data sets collected by the National Marine Fisheries Service can be used to measure the impact of changes in biological and economic conditions on the size and structure of the fleet.

Methodology

Changes in the size of the fishing fleet can be modeled assuming that (1) firms attempt to maximize profits in a (2) highly competitive market utilizing (3) a common property resource and (4) subject to a yield curve that is logarithmic in effort. A model of a fishery based on these assumptions is presented in Figure 1 where fishing effort (E) is represented on the horizontal axis and the dollar value ($) is on the vertical axis. Initially, the intersection of total revenue (TR) and the total cost (TC) determines the common property fishing effort level (EOA). The private property, profit maximizing level of effort (Ep) occurs where marginal cost is equal to marginal revenue; where MC_1 is tangent to TR. If prices increase relative to costs, the total revenue curve shifts upward to TR'. The new private property, profit maximizing level of fishing effort occurs at Ep' where MC_2 is tangent to TR'. The slopes of MC_1 and MC_2 and hence marginal cost are equal because total cost (TC) has not changed. In the open access, common property case, the new equilibrium occurs at EOA' where total cost (TC) equals the new total revenue (TR'). In Figure 1, not only is the level of fishing effort higher in the open access case, but the change in effort for a given price increase is much larger than in the case where property rights exist in the fishery.

[1]This is an interim report of a continuing study of the Gulf of Mexico shrimp fishing fleet.

The model in Figure 1 can be presented as a profit maximization problem subject to an output constraint as in equation (1). Profits (P) are equal to total revenue (TR)

$$\pi = TR - TC + \mu(Y - qx\ \ln E) \qquad (1)$$

where π = profit
TR = total revenue
TC = total cost
Y = yield or output
q = catchability coefficient
x = biomass level
E = fishing effort
μ = Lagrangian multiplier

minus total cost (TC) for a given level of output (Y = qx lnE). Relaxing the output constraint by one unit would increase profits by the factor m . Fishing effort (E) is assumed to be linear[2] and composed of variables representing fishing behavior and vessel characteristics. Equation (2) indicates that total fishing effort

$$E = \beta_1 + \beta_2 T + \beta_3 GT + \beta_4 C + \beta_5 VL + \beta_6 FS \qquad (2)$$

where E = fishing effort
T = trips
GT = gross tonnage
C = crew size
VL = vessel length
FS = fleet size

(E) is a function of fishing behavior (trips and crew size), vessel characteristics representing the structure of the fleet (gross tonnage, vessel length), and fleet size. The marginal contribution of each factor input to total effort is represented by β_2 to β_6 and the minimum effort level necessary for producing an output is represented by β_1. Total cost is also assumed to be linear in fishing behavior and vessel characteristic variables as in equation (3). The fixed cost of operating in the shrimp fishery are

$$TC = r_1 + r_2 T + r_3 GT + r_4 C + r_5 VL + r_6 FS \qquad (3)$$

represented by r_1 and r_2 to r_6 are the unit costs of each factor of production. Lastly, total revenue in equation (4) is simply the price per pound of shrimp (P) multiplied by the yield or output from the fishery.

$$TR = P\ Y \qquad (4)$$

[2]This simplistic assumption proved untenable and has been replaced with a more sophisticated and realistic assumption describing fishing effort in subsequent research.

Since effort is a function of fleet size, fleet size can be used to measure changes in effort if the other fishing behavior and vessel characteristic variables are held constant. This derived demand for the size of the fleet that results in maximum profits can be estimated by substituting equations (2) through (4) into equation (1), setting the derivative of profits with respect to fleet size equal to zero, and then solving for fleet size:

$$FS = -\beta_1/\beta_6 + pqx/r_6 - \beta_2/\beta_6\ T - \beta_3/\beta_6\ GT - \beta_4/\beta_6\ C - \beta_5/\beta_6\ VL \quad (5)$$

For a given resource level (qx), according to equation (5), the optimal fleet size that maximizes profits is determined by the ratio of exvessel prices (P) to the unit cost of maintaining the fleet (r_6). However, as the other effort components (trips (T) or gross tonnage (GT), for example) increase, the size of the fleet necessary to maintain the same total level of effort declines by the value of their coefficients.

The coefficient for the relative price variable (pqx/r_6) provides information about the common property, open access nature of the shrimp fishery resource. If profits were being maximized in a fishery characterized by property rights, the value of this coefficient would be equal to one as theorized in equation (5). However, because individual fishermen do not internalize the value of the fishery (pqx) in their production decisions, the estimated value of this coefficient should be greater than and statistically different from the value of one in the common property case as reflected in Figure 1. The difference between the theoretical and estimated values of this coefficient should provide an estimate of the common property externality effect on fleet size. A comparison of the expected values of this coefficient and the signs of the other independent variables between the theorized and estimated models should also indicate the accuracy of the models underlying assumptions.

Analysis

The data set for this analysis was generated using the vessel operating units file and shrimp landings file for vessels operating in the Gulf of Mexico shrimp fishery as maintained by the National Marine Fisheries Service.[3] Fleet size, vessel entry and exit behavior, and vessel characteristics were determined by accessing the information in the vessel operating units file. The shrimp landings file provided economic, biological, and fishing behavior data. This information was combined in a data set covering the 1966 to 1979 time period.

The information on the unit cost of maintaining a fleet of vessels (r_6) necessary for estimating the derived demand curve in equation (5) was not readily available. This unit cost should correspond to the interest paid on the vessel's construction loan and, therefore, should be closely related to the interest rate on that loan. Since interest rates

[3]Ward (1989) provides a complete discussion of this data set.

generally fluctuate with the prime rate, an average of the prime rate corresponding to the year the vessel was constructed should approximate this unit cost. The unknown catchability coefficient (q) and the biomass level of shrimp (x) were approximated by the annual average landings per vessel based on the assumption that shrimp was a fully developed resource (Nicholes, 1986) holding the effect of above and below average fishing years constant. Lastly, a fuel price index was included in the model to absorb the impact on fleet size of the dramatic increase in prices and reduced availability of fuel in the 1970's.

The estimated model in equation (6) has been adjusted for serial correlation and heteroscedasticity. The signs of the

$$\underset{}{FS} = \underset{(55.9)}{-17{,}670.1} + \underset{(73.0)}{3.14\, pqx/r_6} - \underset{(86.3)}{355.9\, T} - \underset{(16.1)}{300.8\, GT} - \underset{(45.2)}{89.6\, C} \qquad (6)$$

$$- \underset{(209.5)}{712\, VL} - \underset{(71.4)}{4.2 AA} - \underset{(64.2)}{2.7\, BA} + \underset{(72.5)}{22{,}791.2\, DAA}$$

$$+ \underset{(65.8)}{19{,}332.8\, DBA} + \underset{(75.6)}{4.81\, Fuel}$$

where

adjusted r-squared = 0.99
$F_{12,1}$ = 999,999
T = trips
GT = gross tons
C = crew size
VL = vessel length
FUEL = fuel price index
FS = fleet size
pqx/r_6 = price cost ratio for a given biomass level
AA = above average year multiplicative dummy
BA = below average year multiplicative dummy
DAA = above average year additive dummy
DBA = below average year additive dummy

coefficients coincide with the theoretical model and the value of the relative price variable was greater than and significantly different from 1 with a 95% confidence interval. The dummy variables AA, AB, DAA, DBA account for the effect of above and below average fishing years[4] on the slope of the relative price variable and on the constant term. The positive and statistically significant fuel price index coefficient indicates that as fuel costs rose, fleet size increased. One explanation for this result is the replacement of large, fuel inefficient vessels with a greater number of smaller, fuel efficient vessels in the fleet. The increased cost of fuel resulted in an increase in fleet size by causing the structure of the fleet to favor smaller, fuel efficient vessels.[5]

[4]An above average fishing year was defined to be above $125 million in total landings value, an average fishing year was between $90 and $125 million in total landings value, and a below average fishing year was set at less than or equal to $90 million in total landings value with value deflated to a 1967 base year.

[5]Alternatively, both fleet size and fuel costs increased over time and the positive coefficient reflects correlation rather than causation.

Results

According to the model presented in equation (6), the value of the relative price variable (pqx/r_6) coefficient is 3.14 times larger than its expected theoretical value. This implies that 3.14 times as many vessels are in the common property, open access fishery than would be in a private property fishery generating the maximum level of profits. For the Gulf of Mexico shrimp fishery, assuming the fishing behavior and structure of the fleet does not change, 68.15 percent of the vessels operating in the fishery would have to exit for the remaining vessels to maximize profits from the resource. This suggests that the fishery is heavily overcapitalized and suffers from excess capacity.

The model also suggests that the optimum fleet size will decline by 355.9 vessels for each unit increase in trips, 300.8 vessels for each unit increase in gross tonnage, 712 vessels for each unit increase in vessel length, and 89.6 vessels for each unit increase in crew size. The relatively large differential between capital and labor induced fleet size changes suggests that shrimp fishing vessels are capital intensive.

The own-price elasticity of demand for the optimum size fleet based on equation (6) calculated at the mean values for each variable was -3.2054. This highly elastic demand indicates that a small decline in the cost of financing the fleet would result in a large increase in the size of the fleet. The exvessel real price (p) and the catchable biomass (qx) elasticities of 3.2054 were also highly elastic. A small increase in the real exvessel price per pound or in the catchable biomass level would result in a large increase in fleet size.

Net entry can be determined by integrating equation (6) with respect to price (p), cost (r_6), and the catchable biomass level (qx). An increase from 94 cents to 95 cents per pound in the real exvessel price of shrimp according to equation (7) would result in the net entry of 21 vessels into the Gulf of Mexico shrimp fishing

$$\int_{0.94}^{0.95} FS\, dP = 1.57\ p^2qx/r_6\ 1\ 17{,}670\ p - 355.9\ TP - 300.8\ GTP - 89.6\ CP - 712\ VLP \tag{7}$$

fleet if all other variables remained constant. The resulting net benefit per vessel of this one cent price increase would be \$142 each year. According to equation (8), an increase of one point in

$$\int_{4.49}^{4.50} FS\, dr_6 = 3.14\ pqx(\ln r_6) - 17{,}670\ r_6 - 355.9\ Tr_6 - 300.8\ GTr_6 - 89.6\ Cr_6 - 712\ VLr_6 \tag{8}$$

the cost of financing the fleet from an interest rate of 4.49 to 4.50 percent would result in a decline of 20 vessels in the size of the fishing fleet. The resulting annual net benefit per vessel of this one point decrease in the financing cost is $95. Equation (9) indicates that 2,032 vessels would enter the fishery for a one

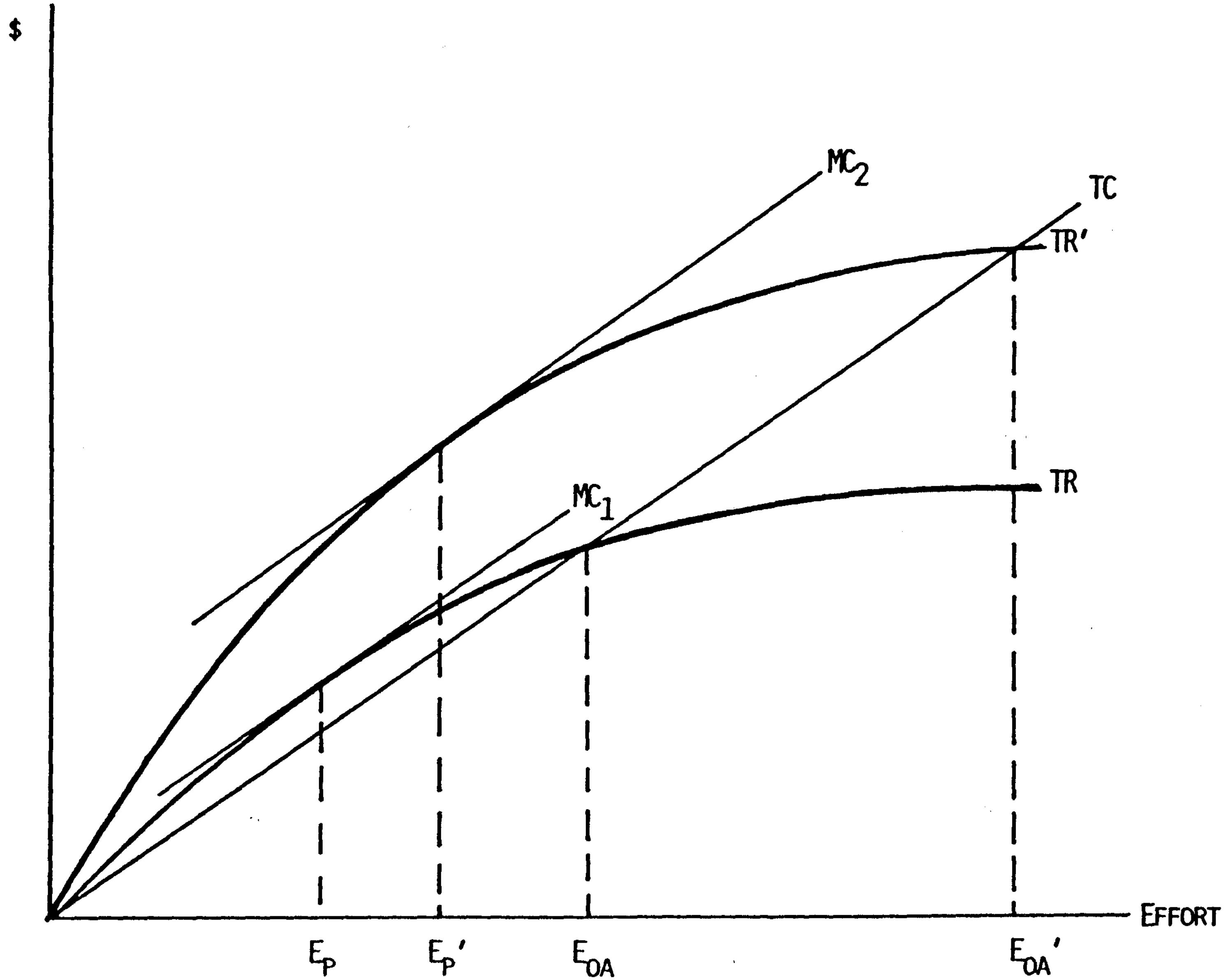
$$\int_{24,179}^{24,180} FS\, dqx = 1.57\ p(qx)^2/r_6 - 17,670\ qx - 355.9\ Tqx - 300.8\ GTqx - 189.6\ Cqx - 712\ VLqx \qquad (9)$$

pound increase in the average annual per vessel landings of shrimp form 24,179 to 24,180 pounds. The resulting annual net benefit per vessel of this one pound increase in average annual landings would be -$6,792. Increases in the price per pound or declines in the cost of financing the fleet appear to generate positive net benefits while increases in per vessel annual landings generate negative net benefits to the fleet if all other factors are held constant.

Conclusions

These preliminary results from an ongoing study of shrimp vessel entry and exit behavior indicate that the fishing fleet does respond to changes in the biological and economic conditions existing in the Gulf of Mexico shrimp fishery. Although additional research needs to be conducted, the strong statistical fit of the observed data supports the model's contention that biological and economic conditions in the fishery determine the structure and size of the fishing fleet through their effect on vessel entry and exit behavior. According to the model in equation (6), 3.14 times as many vessels operate in the common property, Gulf of Mexico shrimp fishery than would operate in the fishery if property rights existed. Also, fleet size declines to maintain the same total effort level as the other effort components are used more intensively in the fishing process. Increases in the real exvessel price (equation (7)) or declines in cost of financing the fleet (equation (8)) result in positive net benefits on a per vessel basis while increases in the level of catchable biomass (equation (9)) yield large negative net benefits per vessel when all other factors are held constant. Lastly, the model's own price (r_6), exvessel price (p), and catchable biomass (qx) elasticity of demand measures indicate a highly elastic derived demand for vessels making up the Gulf of Mexico shrimp fishing fleet. That is, small increases in prices, costs, or the resource level have large impacts on the size of the fleet.

FIGURE 1



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