ENERGY SUBSTITUTION IN THE GULF OF MEXICO SHRIMP FISHERY

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Since 1973, the U.S. economy has shifted from a position characterized by abundant and low-cost energy to one of rising energy prices and fragile energy supplies, periodically threatened by an unstable foreign political environment.

Since competitive firms choose the bundle of inputs that minimizes the total cost of producing a given level of output, higher fuel prices induce an increase in labor and capital inputs and a decrease in energy input to the extent that substitution is possible. High fuel prices encourage energy efficiency through greater capital investment with a corresponding reduction in unit cost. Examples of such investments are retrofitting existing equipment, developing new equipment, or both.

A central issue of energy policy, planning, and analysis is the extent to which other factors of production can be substituted for energy. This can be measured by deriving appropriate elasticities of substitution. If energy and capital are substitutable, then advancing relative prices of energy will increase demand for new capital goods. In this case, investment incentives, such as tax credits or accelerated depreciation allowances, will reduce the price of capital and generate an increased demand for capital and a decreased demand for energy, thereby further expediting the adjustment process. Conversely, if it is found that possibilities for substitution between energy and nonenergy inputs are limited, the unit cost of output will rise as energy prices rise.

The estimation of substitution elasticities among energy and nonenergy inputs is the subject of several current economic studies in manufacturing processes. Studies on energy substitution have been done by Berndt and Wood, Halvorsen and Ford, and Field and Grebenstein for the United States; by Fuss for Canada; and by Griffin and Gregory, and Pindyck for several countries. Capital and energy have been shown to be good substitutes in many industries. Hence, conservation efforts on the replacement of vintage facilities seem well advised.

The energy share of total cost is generally much higher in fishing than in manufacturing. Moreover, unlike manufacturing, the fishing industry is based on seasonal biological processes. Any disruption in the availability of fuel at a reasonable price during the fishing season is likely to adversely affect the fishing industry because production cannot be made up in the off-season. However, no studies on energy substitutability in the fishing industry have been conducted. The lack of studies on the substitution possibilities between energy and nonenergy inputs leaves a void in the appropriate information upon which public policy, business management, and investment decisions can be made.

In this paper, the elasticities of substitution among fuel, capital, and labor are estimated for the Gulf of Mexico Shrimp fishery. Fuel costs in the Gulf shrimp fishery account for a relatively high percentage of total costs compared to other kinds of fishing (Noetzel; Penn). The equipment used to harvest shrimp is diverse and fuel efficiencies differ with type vessel, vessel size, and the area shrimped. Elasticities of substitution will be estimated for different vessel sizes by specifying the translog cost function fit to observed data.

DESCRIPTION OF THE FISHERIES

The states bounding the Gulf of Mexico (Figure 1), Florida, Alabama, Mississippi, Louisiana, and Texas, produced approximately 61 percent (208.3 million pounds) of U.S. shrimp landings (339.7 million pounds) in 1980. The cost of fuel has become the most rapidly increasing and perhaps the largest single item of cost. Fuel costs tripled between 1971 and 1977, and fuel prices increased approximately 88 percent from 1977 to 1980. Consequently, fuel costs for a 66–70-ft. vessel, as a percent of total costs, increased from 9 percent in 1971 to 32 percent in 1980, while labor costs

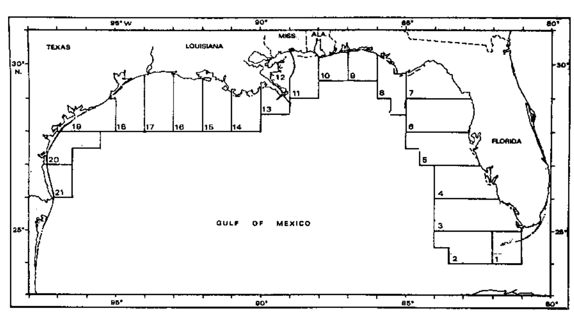

Figure 1. Statistical Area Used in Reporting Gulf Coast Shrimp Data

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declined from 34 percent to 31 percent, and capital cost dropped from 33 percent to 14 percent (Swartz). In broad terms, fuel prices have increased over sixfold since 1973, against an almost twofold increase in the prices of other commodities.

Two major trawl fisheries of the Gulf of Mexico/U.S. Continental Shelf are an inshore fishery landing small shrimp for food and bait, and an offshore fishery landing large shrimp for food. The price of shrimp per pound tends to be higher as the size of shrimp increases; therefore, when comparing inshore and offshore shrimp fisheries, more gross revenue per pound of shrimp is realized from the offshore catch than from the inshore catch. The total inshore and offshore shrimp landings in pounds have remained relatively constant over the past decade, but the total shrimp landings in dollar value have increased much faster offshore than inshore (Figures 2 and 3).

A significant portion of the inshore catch is taken by part-time fishermen. Trawls, wing nets, or both are used from small craft to harvest shrimp inshore. Offshore fishing vessels tow from two to four shrimp trawls, fish more hours, travel further to their fishing grounds, and are generally operated by full-time shrimpers. The number of vessels has increased, along

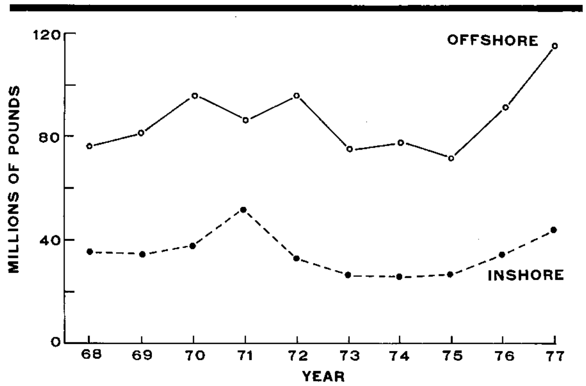


Figure 2. Inshore and Offshore Shrimp Landing in Pounds from the Gulf of Mexico, Heads-off, 1968–77

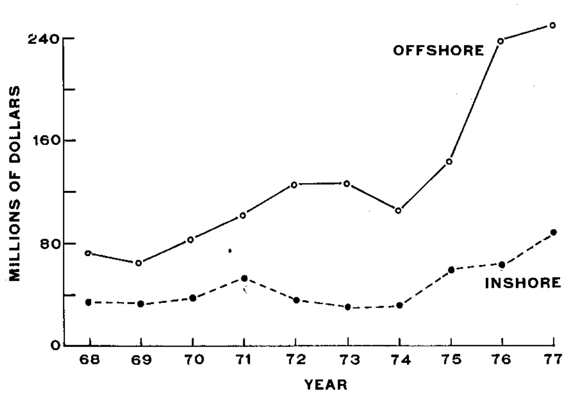


Figure 3. Value of Inshore and Offshore Shrimp Landings in Dollars from the Gulf of Mexico, 1968–77

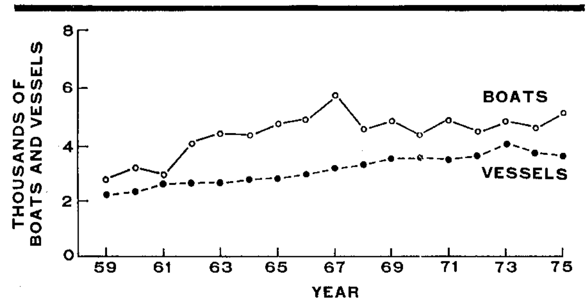
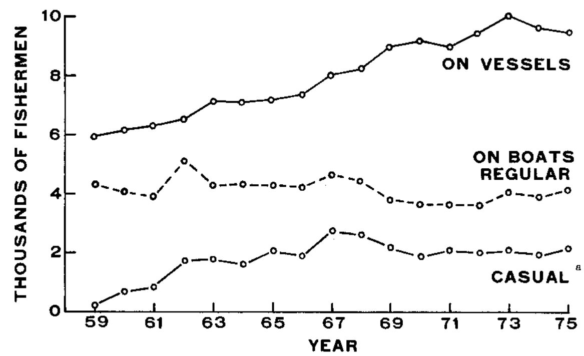


Figure 4. Reported Annual Number of Shrimp Boats (Less than 5 Net Registry Tons) and Vessels (5 Net Registry Tons or Larger) in the Gulf of Mexico, 1959–75



[a] Occasional or part-time fishermen on boats.

Figure 5. Reported Annual Number of Shrimp Fishermen on Boats (Less than 5 Net Registry Tons) and Vessels (5 Net Registry Tons or Larger) in the Gulf of Mexico, 1959–75

with employment (Figures 4 and 5). Although medium-sized vessels can shrimp onshore and offshore, many vessels are too large to operate effectively inshore. As vessel size increases and offshore shrimping dominates a vessel's activities, the number of hours per trip that the trawls are at sea increases.[1]

Abruptly rising fuel costs have the greatest impact on the activities of fishermen accustomed to shrimping in areas distant from their home ports. Larger vessels are more likely to shrimp in deep water and travel to waters off adjoining states. Both shrimping strategies of the larger vessels result in the use of more fuel than is used by medium-sized vessels. In 1978, a day of fishing effort cost large vessels approximately $100 more than it cost medium-sized vessels (Roberts and Sass).

Three different size groups of vessels are involved in the Gulf shrimp fishery: (1) small-sized boats shrimping entirely inshore, (2) medium-sized vessels shrimping inshore and offshore, and (3) large-sized vessels shrimping entirely offshore. These groups harvest shrimp of different sizes, with corresponding differences in prices and revenue, and use different amounts of capital, labor, and fuel in producing a given level of output. Therefore, the extent to which capital

[1] The number of hours increases from seven hours on an average inshore trip to three to ten days per offshore trip (National Marine Fisheries Service, *Gulf Coast Shrimp Data Annual Summary*, Table 2, interviewed craft).

and labor can be substituted for fuel would differ by vessel group or vessel size. To estimate elasticities of substitution, the fishing crafts are classified into three categories according to length of hull, which is a good indication of fishing power in waters of various depths. Hull length is closely associated with engine horsepower, net size, and fishing power (Blomo et al.).

Small shrimp fishing craft (less than 40 ft.) include both *vessels* (commercial fishing craft having a capacity of 5 net tons or more, and documented or enrolled by the U.S. Coast Guard) and *boats* (commerical fishing craft of less than 5 net tons), as reported in statistics of the National Marine Fisheries Service (NMFS). These small fishing craft are used almost entirely for inshore (bay) fishing. They have lower catches and fish fewer days per year and fewer hours per trip than larger craft. They also have one- or two-person crews, many of whom are part-time fishermen depending primarily on other sources of income.

Medium-sized shrimp fishing craft (40–65 ft. hulls) are mostly *vessels.* They have two- to three-person crews, and they fish in both inshore and offshore waters. Roughly two-thirds of the vessels landing shrimp in the Gulf of Mexico region are of this type.

Large shrimp fishing craft (greater than 65-ft. hulls) are all *vessels,* largely of steel hull construction. They fish mostly in offshore (Gulf) waters. These larger craft operate with three- or four-person crews, have a more complete complement of electronic equipment, often have freezer rather than ice storage for shrimp in their holds, fish more days per year and more hours per trip than the medium- or small-sized shrimp craft, fish farther from port, and are able to catch larger shrimp with correspondingly higher prices.

METHODOLOGY AND EMPIRICAL RESULTS

The functional form selected for the investigation is the translog cost function developed by Christensen et al. This function is highly suitable for this study because it entails no prior restrictions on parameters.

We have specified a three-input, constant-return-to-scale cost function $C = c(P_K, P_L, P_E)$ where C is production cost and the P's refer to the prices of capital (K), labor (L), and fuel (E). The cost share of each input is a function of its own price and the prices of its substitutes. This involves estimating equations (see Appendix) of the form:

$$(1) \quad S_i = \alpha_i + \Sigma_j (\gamma_{ij} \ln P_j) + u_i \quad \text{for } i, j = K,L,E$$

where S_i is the share of the i^{th} input in total cost, α_i and γ_{ij} are parameters, and u_i represents error terms.

The elasticities of substitution are of primary interest to this study. Brendt and Wood show that the Allen Partial Elasticities of Substitution (PES) can be calculated as follows:

$$(2) \quad \sigma_{ij} = \frac{\gamma_{ij} + S_i \cdot S_j}{S_i \cdot S_j}.$$

Because the elasticities of substitution are functions of cost shares, they will vary across the sample. Rather than report the estimated elasticities for each observation, the elasticities are evaluated at the means of the data. Negative signs of the estimated elasticities of substitution indicate complementarity in production, and positive signs indicate substitution (Berndt and Wood).

The data required for the estimation of the share equations include the prices and annual cost shares of capital, labor, and fuel for the Gulf of Mexico shrimp vessels. Fixed costs of vessels and fishing gear are considered as the capital share, while food, wages, and other business overhead expenses are treated as the labor share. Diesel fuel costs are considered as the energy share. These shares and input price data are taken from a study of cost and earnings of bay shrimp fishermen in Louisiana (Duffy) and Florida-based Gulf of Mexico shrimp trawlers (Blomo and Griffin). All data are for the calendar year 1977. The fuel price is represented by the price of diesel fuel at $0.425 a gallon, the capital price at an 8.75 percent interest rate, which is applied to the financing of construction and refurnishing of fishing vessels, and the labor price by an estimated $10.00 per hour for shrimp fishermen. Prices are assumed to be the same for all fishing craft. The average cost shares of small vessels are 0.25 for fuel, 0.23 for labor, 0.24 for capital, and 0.28 for ice and others. Those of medium-sized vessels are 0.26 for fuel, 0.19 for labor, 0.39 for capital, and 0.16 for ice and others. Those of large-sized vessels are 0.29 for fuel, 0.15 for labor, 0.40 for capital, and 0.16 for ice and others.

Under the assumption of weak separability, we omit ice and other input in the estimation of share equations. The economic implication for weak separability is that the omission of ice and other are assumed to be invariant to the productivity of other input factors and, therefore, is assumed to be independent of the elasticity of substitution of capital, labor, and energy (Griffin and Gregory). Hence, small-sized vessels are labor intensive, while larger vessels are more energy and capital intensive.

To estimate the parameters α_i and γ_{ij} in equation (1), 15 vessels were selected as observations for each of three different size classes. The disturbances in the equations are likely to be correlated because random deviation from profit maximization should affect the markets for labor, capital, and energy. Thus, equation (1) is estimated with the Iterative Zellner Efficient Estimation (IZEF) method, which is equivalent to a maximum likelihood estimation (Zellner). Parameter estimates for the functions are given in Table 1.

The pseudo-R^2 statistics are 0.988 for small, 0.473 for medium, and 0.111 for large vessels. As vessel size increases, the value of the pseudo-R^2 decreases. In evaluating the parameter estimates, a large portion of medium-sized vessels do not achieve statistical significance by t-statistic at the 5 percent level. The smaller value of the pseudo-R^2 for larger vessels and the high standard error for medium-sized vessels seem to be correlated with the fishing circumstances of each size

Table 1. Estimated Parameters of Translog Cost Function

Parameter [a]	Boat (under 40 ft)	Medium Class Vessel (40-66 ft)	Large Class Vessel (over 66 ft)
K	-.090 (.009)	-.148 (.024)	-.465 (.011)
L	-.084 (.008)	.047 (.025)	-.008 (.011)
E	1.174 (.007)	1.100 (.005)	1.473 (.011)
KK	.020 (.011)	.007 (.024)	.056 (.001)
LL	.056 (.006)	.021 (.001)	.005 (.001)
EE	.156 (.001)	.001 (.001)	.095 (.001)
KL	.040 (.001)	-.014 (.024)	.017 (.001)
KE	-.060 (.001)	.006 (.024)	-.073 (.001)
LE	-.097 (.100)	-.007 (.024)	-.022 (.001)
Pseudo R^2 [b]	.988	.473	.111
Number of Observations	15	15	15

Figures in parentheses are asymptotic standard errors.
[a] K=Capital; L=Labor; E=Fuel
[b] The Pseudo R^2 is calculated as $1 - |R_1|/|R_2|$ when $|R_1|$ is the determinant of the estimated residual convariance matrix and $|R_2|$ is the determinant when all of the slope coefficients (γ_{ij}) are constrained to be zero. The Pseudo $-R^2$ is used, because the IZEF estimation method is applied to estimate the translog cost functions.

of vessel, operation patterns, and the variability and diversity of the data. Small-sized vessels are always involved in one inshore fishing circumstance. Medium-sized vessels are fishing in two different circumstances, inshore and offshore. Large vessels are shrimping in numerous different circumstances because they travel to waters off different states. In addition, the data for medium-sized vessels have high standard deviations between the sets of inshore and offshore operations.

A cost function is well behaved if it is concave in input prices and if its input demand functions are strictly positive. The translog cost function does not satisfy these restrictions globally. Therefore, the fitted translog form must be checked for positivity. The positive input demand condition is satisfied if the fitted cost shares are positive. Concavity of the cost function is satisfied if the Hessian matrix is negative semidefinite. Since both conditions are satisfied in this case, we conclude that our estimated translog cost functions are well behaved.

To measure factor substitution possibilities, the Allen Partial Elasticities of Substitution (PES) were calculated for the three different class vessels. Results are given in Table 2. Several important conclusions emerge. First, capital and labor are substitutable; the estimated capital-labor elasticities of substitution (σ_{KL}) range from 0.228 to 2.136. Second, labor and energy are less substitutable, with an estimated elasticity of substitution (σ_{LE}) ranging from 0.241 to 0.876. Third, capital and energy display considerable substitutability. Small craft have an estimated capital-energy sub-

Table 2. Allen Partial Elasticities of Substitution by Vessel Classes

	Vessel Length (feet)		
Partial Elasticities of Substitution [a]	Less than 40	40-65	Over 65
KL	1.720	.228	1.309
KE	.203	1.041	.658
LE	.288	.876	.241

[a] K=Capital, L=Labor; E=Fuel
[a] Partial Elasticities of Substitution

stitution elasticity of 0.203. For medium-sized vessels, this elasticity is 1.041 and for large vessels, 0.658. Hence, if the fuel/capital price ratio increases by 10 percent, the capital/fuel input ratio would increase by 2 percent for small craft, 10 percent for medium-sized vessels, and 6 percent for large vessels. From these results, the medium-sized vessels show the highest capital/energy substitutability.

Shrimping seasons for inshore and offshore areas are different. Small craft can shrimp effectively during the inshore season, but are less effective during the offshore season. For large vessels, the opposite is true. However, medium-sized vessels can shrimp effectively in both seasons. Therefore, compared with medium-sized vessels, small and large vessels use more fuel per unit of shrimp catch because they search for shrimp in the off-season. Medium-sized vessels, on the other hand, use relatively more capital intensively and have a higher potentiality for capital substitution for energy. The important economic implication resulting from these estimates is that increases in the fuel/capital price will lead to a substitution of capital for fuel and thereby to a relative increase in the capital input and relative decrease in fuel input. Thus, the capital/fuel input ratio will increase.

MANAGEMENT IMPLICATIONS

Some policy implications can be derived from these empirical results. Since capital substitution for energy (σ_{KE}) and the labor substitution for energy (σ_{LE}) are positive, an increase in the relative price of fuel to capital and/or labor will lead to an increase in capital and/or labor input relative to fuel input. Moreover, investment incentives, such as tax credits and accelerated depreciation allowances, reduce the price of capital services, thereby increasing the relative price of fuel to capital and accelerating capital substitution for fuel. Furthermore, such fiscal incentives will generate an increased demand for capital and decreased demand for energy under *ceteris paribus* conditions, for example, holding output constant. Therefore, to the extent that energy conservation becomes a conscious policy goal, incentives to increase capital investment in shrimping, while holding output constant, will lead to a relative decrease in the energy input required.

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APPENDIX

Translog Cost Function

A translog function relates the flow of gross output (Y) to the services of three inputs: capital (K), labor (L), and energy (E). It may be rewritten by applying duality in terms of total cost (G) and three input factor prices, P_K, P_L, and P_E, as:

$$\text{1A)} \quad \ln G = \ln \alpha_0 + \ln Y + \alpha_K \ln P_K + \alpha_L \ln P_L + \alpha_E \ln P_E + 1/2\, \gamma_{KK} (\ln P_K)^2 + \gamma_{KL} \ln P_K \ln P_L + \gamma_{KE} \ln P_K \ln P_E + 1/2\, \gamma_{LL} (\ln P_L)^2 + \gamma_{LE} \ln P_L \ln P_E + 1/2\, \gamma_{EE} (\ln P_E)^2$$

where α_O denotes the states of technology, Y output, and α_i and γ_{ij}, parameters.

Assuming perfect competition in the factor markets, input prices are treated as fixed. Given the level of output, cost-minimizing input demand functions are derived as follows:

First, logarithmically differentiate (1) above:

$$\text{2A)} \quad \frac{\partial \ln G}{\partial \ln P_i} = \frac{\partial G}{\partial P_i} \cdot \frac{P_j}{G} = a_i + \Sigma (\gamma_{ij} \cdot \ln P_j)$$

$$i,j = K,L,E$$

And then, using Shephard's Lemma, which assumes cost minimization and perfect competition in factor input markets:

$$\text{3A)} \quad X_i = \frac{\partial G}{\partial P_i}; i = K,L,E$$

where X_i is the cost minimizing input quantity of capital, labor, and energy. This gives a series of three input cost share equations;

$$4A)\quad S_K = \frac{P_K X_K}{G} = \alpha_K + \gamma_{KK} \ln P_K + \gamma_{KL} \ln P_L + \gamma_{KE} \ln P_E$$

$$S_L = \frac{P_L X_L}{G} = \alpha_L + \gamma_{LK} \ln P_K + \gamma_{LL} \ln P_L + \gamma_{LE} \ln P_E$$

$$S_E = \frac{P_E X_E}{G} = \alpha_E + \gamma_{EK} \ln P_K + \gamma_{EL} \ln P_L + \gamma_{EE} \ln P_E$$

where the P_iX_i/G term will be the factor cost shares of the ith factor since

$$5A)\quad G = P_K X_K + P_L X_L + P_E X_E.$$

From the accounting indentity that the input shares sum to unity, the sum of the share changes in response to a price change for a given input must be zero, and therefore the translog cost function must meet the following conditions:

$$6A)\quad \alpha_K + \alpha_L + \alpha_E = 1$$

$$\gamma_{KK} + \gamma_{KL} + \gamma_{KE} = 0$$

$$\gamma_{LK} + \gamma_{LL} + \gamma_{LE} = 0$$

$$\gamma_{EK} + \gamma_{EL} + \gamma_{EE} = 0$$

In addition, partial differentiation of (1A) reveals the following symmetry condition:

$$7A)\quad \frac{\partial^2 \ln G}{\partial \ln P_i \cdot \partial \ln P_j} = \gamma_{ij} = \gamma_{ji} \quad ji,j = K,L,E$$

Combining (5A) and (7A) insures that estimation of any two equations in (4A) will yield all parameters of the translog cost function. Thus, the first two equations were estimated for the investigation. Because random deviations from profit maximization would affect factor markets of labor, capital, and energy, the disturbance terms in (6A) are likely to be correlated. In order to achieve efficient estimators, the Zellner efficient estimation producer was applied (Zellner).