PRODUCTION ANALYSIS OF COMMERCIAL FISHING IN THE LOWER AMAZON

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Over the last thirty years the commercial fisheries of the Amazon has undergone major changes. Today Amazon commercial fisheries are estimated to employ some 50000 people and generate between 100 and 200 million dollars at first sale. The commercial fishery is now an important sector of the regional economy and a major source of employment for the urban and rural population along the Amazon river and its major tributaries. However, despite the importance of Amazon fisheries, they have received little attention from development planners.

In an earlier study Almeida et al. (in press) undertook an economic analysis of the fishing fleet supplying the Lower Amazonian city of Santarém, the fourth largest fish market in the Brazilian Amazon. This study found that while there is little variation in fishing technology, the fleet could be divided into two main groups corresponding in many ways to the classic formal informal sector dichotomy, with larger, better equipped boats supplying export oriented fish processing plants and smaller boats supplying the local consumer market. Despite the apparent technical superiority of the larger boats, the study found that smaller boats were actually more profitable. This result is all the more interesting because many of these fishers are exploiting floodplain lakes that are controlled and in some cases managed by local communities. This study analyzes the economics of the fishing operations of the Santarém fleet with the objective of contributing to the formulation of policies in support of the region's small scale floodplain lake fisheries.

Methodology

Production Model

A Cobb-Douglas regression model was used to estimate the production function of Lower Amazonian commercial fishers. This is a conventional model where the level of production depends on the level of input use (Varian, 1999; Ferguson, 1996). The advantage of using the Cobb-Douglas function is its reasonable proximity with economic theory and facility for calculating the partial elasticity of output with respect to input and returns to scale (Ferguson, 1996). The Cobb Douglas model has the following form:

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$$Y_i = aK^{b_1} L^{b_2} C^{b_3} G^{b_4} e^{\mu}$$

where, for the i^{th} boat:

Y_i = Gross Revenue (R$/ fishing trip);
K_i = Fixed capital depreciation of inputs including boat and gears. (R$/ trip);
L_i = labor inputs (number of fishermen per trip);
C_i = fuel inputs (R$/trip);
G_i = ice inputs (R$/trip);
a = intercept parameter;
b_1, b_2, b_3 e b_4 = partial elasticity of production with respect to each input;
e = base of natural logarithm
$\mu\, i$ = error term;
i = 1….2845

Two dummy variables were considered in the model: one for gear type and the other for market type to evaluate the impact of these two variables over the production function. The first dummy variable was included to account for differences in type of market: fishing processing plant (1) and the regional market (0). The second dummy variable was introduced to capture differences between the productivity of nets (1) and other more artesanal gears such as the bow and arrow, cast net, fishing pole, harpoon and long line (0).

The model presented here is based on a series of assumptions. First, each boat owner seeks to maximize profit, choosing the best combination of inputs according to their relative prices to produce the amount of output that maximizes profit. Second, markets for inputs and outputs are perfectly competitive. Third, boat owners are price takers in both markets and no individual boat owner's behavior affects prices. Fourth, all boat owners have perfect information about the market, so they know the prices of all inputs. Finally all input are the same quality for all boats.

Input marginal productivity (IMP) shows how much revenue will vary when one input varies, keeping all others constant. The IMP of each class of boat was calculated based on the average revenue, the cost of each input for the different sizes of boat and based on the elasticity of the Cobb-Douglas model.

Landing Data

The landing data used to characterize the Santarém fishing fleet were collected daily during 1997 (Projeto IARA/IBAMA). Interviews were undertaken by four people located at the main landing sites along the waterfront (markets and processing plants) during the peak hours of fish landings. Interviews included information on the characteristics of the fishing vessel, trip itinerary, catch size and composition, number of fisherman and canoes, duration of the voyage, ice and fuel consumption, and the sale price of fish. The original data base consists of a total of 2992 landings, of which 2845 were used in this study. The remaining 147 were deleted because of incomplete data.

Values for gear and canoes are based on Santarém market prices and interviews with boat owners (see Table 1). The value of boats is derived from a regression equation based on 50 interviews relating ice storage capacity to the value of the boat. This equation was then used to estimate the value of the boats in the landing data given the storage capacity of each boat. Capital in the model was calculated as the depreciation of the boat, gear and canoes for each trip. The prices for fuel and ice were collected in Santarém during 1997.

RESULT AND DISCUSSION

Production function of fishing fleet

Commercial fishing activity is conducted using a boat that has either a built in storage compartment or removable a wooden box lined with styrofoam. The boat is used to store and transport fish, and fishing itself is done in canoes by pairs of fishers. In large boats, fishing gear and canoes are usually supplied by the boat owner, while in smaller boats fishers may use their own gear and canoe. The boat owner covers the expenses of the voyage (food, fuel, ice and material to fix gear) and purchases the fisher's daily catch at a price which is usually calculated as a percent of the prevailing market price for each species (Almeida *et al*., in press; Isaac *et al*., 1996, Ruffino et al., 1998; Ruffino, in press).

The Cobb-Douglas model was run using the complete fish landing data set with revenue as the dependent variable, ice, labor, fuel, capital, and the level of the river as independent variables and with the two dummy variables.

The resulting model has good explanatory power (Model 1, Table 2). The R^2 is 0.61 and the overall significance is also high (F value = 643.97). Coefficients for all independent variables were positive and less then one. Input elasticity in relation to revenue can be read directly from the coefficient in the Cobb-Douglas Model. The high elasticity of ice (0.45) and fishers (0.34) indicates that they contribute in a fundamental way to production. Fuel and capital, although significant (at $p<0.01$), are less important (coefficients equal or smaller than 0.13).

The other independent variable, river level, showed a high negative correlation with catch in an earlier study (Isaac *et al*., 1996). In 1997, river level was highest (8.26m) in May and lowest in October (1.68 m), with an amplitude of almost 7 meters. Since the vulnerability of fish increases as river level declines, we introduced this variable to capture the effects of environmental change on fisher income. The model shows a low but significant negative coefficient (-0.08). This means that as the river level falls there is a small increase in revenue (Model 1, Table 2).

The model also considered two dummy variables. The dummy variable for market has a high negative value (-0.27; pvalue<0.01) indicating that boats which sell in the regional market obtain higher revenues than boats which sell to the fish processing plant. This analysis confirms the conclusion of an earlier study (Almeida *et al.,* in press) that boats which sell in the regional market have higher revenues in relation to costs than those which sell to fish processing plants. The dummy variable for gear showed that boats that use nets have slightly lower revenue than boats that use traditional gear such as the harpoon, cast net, longline, and fishing pole (coef= - 0.10).

As can be observed in Table 3, modern gear types such as gillnets, purse seines and drift nets are more productive, varying from 12kg/fisher/day up to 47kg/fisher/day (purse seine is used basically in the state of Amazonas) than traditional gear. Productivity of these types of fishing gear varies from 2.8 kg/fisher/day for hand lines up to 19 kg/fisher/day for cast net. Given these differences in productivity, we would expect that the revenue of boats with nets would be greater, however, the opposite is the case. It is possible, that the lower cost of traditional gear (from R$5 to R$100) when compared to nets (from R$85 to R$800) accounts for this different pattern in revenue.

The four inputs considered in the production function were found to be important to revenue generation: ice, fuel, fishers and cost of capital. In the present model, capital, represented by the value of depreciation, and capital remuneration to the boat, gear and canoes, were less important then ice and fishers and equivalent in importance to fuel. In regions where access to capital is limited, the expectation is that this input will be more important than other factors, as is the case in other sectors of the economy (Arima, 1997). One possible explanation for the low elasticity of capital in the production function is that smaller boats have proportionately higher revenue than larger boats, due to the fact that smaller boats tend to concentrate on species with a high value in local markets, compared to those exploited by larger boats.

Returns to Scale

Estimation of returns to scale is important because it indicates at what scale firms are most efficient. In the Cobb Douglas model, if the sum of the coefficients is larger than one, the production function has increasing returns to scale. If the sum of the coefficients is less than one, returns to scale are decreasing, while if they are equal to one, there are constant returns to scale (Varian, 1999; Ferguson, 1986).

In this model the sum of the coefficients is equal to 1, indicating that there are constant returns to scale in production. However, when we tested the hypothesis that the sum of the parameters obtained in the model was equal to one (null hypotheses), using the F test approach, the null hypothesis was rejected (The calculated statistic F was 238 while F critical was 3.84, with significance=0.05). Based on this result we can not say that there are constant returns to scale. However, since the sum of the coefficients is very close to one, we can conclude that returns to scale are very nearly constant.

This result is also consistent with the high degree of technological homogeneity found in the Santarém fleet. Despite great differences in the size of boats, they all use the same technology, two fishers and a canoe and with some type of gill net, in more or less the same fashion. Another indirect indicator, is the large number of small, medium and large boats operating together in the Santarém fleet. If returns to scale were increasing or decreasing, either larger or smaller boats would find it increasingly difficult to compete, something which does not appear to be occurring.

Input Marginal productivity (IMP)

Input marginal productivity is a measure of how revenue varies when one input varies, while maintaining all others constant. The objective of this analysis is to determine how an increase in one of the inputs affects revenue per trip for boats different size classes. The input marginal productivity was calculated for the 5 categories of boats identified in the earlier study (Almeida et al., in press). Boats smaller then 1 t consumed an average of 32 liters of fuel in a 5 to 6 day fishing trip. These boats carry 433 kg of ice and caught an average of 286 kg of fish with 5 fishermen. The average cost of each input was used with its respective coefficient from Model 2 (Table 2), capital (0.116), ice (0.412), fuel (0.112) and number of fisherman (0.362), to calculate the IMP.

The result is shown in figure 1. Of the three inputs (capital, fuel and ice), ice shows the larger marginal productivity. This means that, an investment in ice, everything else being constant, will bring a higher increase in revenue than an increase in any other input for boats of any size class. Comparing size classes, smaller boats presented a higher IMP than larger boats. While marginal productivity of capital is one and half times larger for the small boats than for larger boats, the marginal productivity of ice is more then twice as large. This means that an increase in the amount of ice carried by small boats will result in a greater increase in revenue than an increase of the same proportion for larger boats. Finally, the IMP analysis indicates that, on the margin, inputs are more productive for smaller fishing boats then for larger ones. This is probably due to the fact that capital (fixed and variable) is relatively more scarce for smaller boats than larger ones. Assuming decreasing marginal productivity of inputs, productivity is higher where inputs are scarcer.

Unfortunately, the model could not be run using the cost of fishers due to the high collinearity between estimated cost of this variable and revenue. Consequently, number of fishers was used instead. In contrast to other inputs, the physical marginal productivity of fishers was much lower for smaller boats than for larger ones. This means that fishers are cheaper and labor more abundant for smaller boats. In addition, the number of fishers does not represent a cash outlay for the boat owner since he pays fishers after he sells the catch, and the payment is a proportion of the individual’s catch. So, this input requires a minimal financial investment and so can be utilized fairly abundantly.

The analysis of marginal productivity demonstrates that the different inputs to the fishing trip have different productivities. IMPs for ice, capital and fuel are higher for smaller boats, indicating that these inputs are scarcer for this group than for larger boats. However, while there is a clear difference between large and small boats, there is no clear pattern for intermediate categories. In the case of capital, IMP declines continually for larger boats, raising slightly for boats larger then 15 t. In general the higher IMP of ice, fuel and capital and the smaller marginal product of fishers for smaller boats indicate that there is a substitution of fixed and variable capital for labor in this size class.

River level has been shown in the literature to be positively correlated with catch size in many floodplain fisheries. In this work, however, the influence of river level is negligible for the fleet as a whole. However, if we examine the influence of river level on catch for the two main groups of fishing boats within the fishery, boats larger then 4 t and boats smaller then 4 t, a somewhat different pattern emerges. The relation between catch and river level is positive (0.07) for boats larger then 4 t and negative for boats smaller then 4t (-0.09). The positive relationship for larger boats is probably a result of the predominance of one species, mapara, sold to fish processing plants in March when water level is rising (see figure 2 of Almeida et al., in press). However, the relationship between revenue and river level is negative for both size classes, though stronger for the smaller category (-0.14) than the larger (-0.001). The negative relationship between revenue and river level for larger boats is the probably due to the lower price of mapara. As frequently happens in commercial fisheries, during the period of peak catch, the price of this species can drop to less than half the price paid during the rest of the year.

Implications for fisheries management in the region

The results of this analysis indicate that economies of scale are minimal in the lower Amazonian commercial fishery. The higher labor productivity of larger boats, suggests a pattern of increasing returns to scale. However, this is offset by the more efficient use of ice and fuel by smaller boats. In relation to the use of inputs, this analysis suggests two conclusions. First, that ice and fishers are the critical inputs, while capital and fuel are less important. Second, boats that sell in the regional market have greater revenue relative to costs then the boats that sell to fishing processing plants. This analysis indicates that smaller boats tend to use more labor and less of other inputs when compared to larger boats. For this reason, an increase in these other inputs, such as ice or fuel, of small boats, will result in a proportionally higher increase in revenue than for larger boats. This sensitivity is greater for ice, where the marginal productivity is largest.

There are at least two implications for fisheries development of this analysis. First, the scarcity of rotating capital is a limiting factor for the growth of the fisheries sector. The sector could grow more rapidly and boat owners could increase their revenue if they had access to more capital for variable costs. The high-revenue elasticity in relation to ice shows that it is possible to increase production just by increasing the quantity of ice used. At the same time, the low relationship between revenue and fixed capital (investment) indicates that the sector can expand without major new investments. The low correlation for small boats between ice capacity and boat size (15%) suggests that for much of the fleet it is possible to expand ice capacity by simply increasing the size of the storage compartment (Almeida et al., in press). However, before such measures are considered, the status of individual species of commercial value and their sensitivity to environmental variation must be carefully evaluated on a region by region basis. While fisheries biologists generally consider Amazon fisheries to be under exploited when compared to those of other river systems (Bayley and

Petrere, 1989), several species are thought to be suffering excessive pressure. In the Lower Amazon region, at least four major commercial species, the tambaqui, *Colossoma macropomum,* the surubim, *Pseudoplatystoma tigrinum* (Isaac and Ruffino, 1996; Ruffino and Isaac, 1999), piramutaba (Barthem, 1990; Barthem and Petrere, 1995) and pirarucu (Isaac at al., 1998) are considered to be overexploited. Consequently, measures designed to promote the growth of the fishery must be combined with efforts to insure that these important commercial species are adequately protected.

Conclusion

This paper tends to confirm the findings of an earlier study which found little evidence of economies of scale in Lower Amazonian fisheries. While the model does not indicate constant returns to scale in the regional fishery, the sum of the coefficients is very close to one. With regard to the relative importance of the main inputs to the fishing trip, the study found that ice was most important, followed by fishers, capital and fuel. There are also differences between boats of different sizes. The marginal productivity of capital, ice and fuel is greater for small boats while the physical marginal productivity of revenue in relation to labor is smaller.

In general, the higher coefficients for ice and labor in the model indicate that for both smaller and larger boats there is the possibility of expanding production through increases in rotating capital, while the low coefficient of capital shows that the investment in fixed capital has a relatively small impact on revenue. The low correlation between boat size and ice capacity (55%) suggests that the fleet has the potential to expand production without constructing larger boats. A simple policy aimed at providing fishers with lower cost ice would be the single most effective measure for increasing revenue, and combined with appropriate management measures to protect vulnerable species, could be accomplished without adversely affecting regional fish stocks.

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Table 1. Value and economic life of investiment in gears and canoes (in R$) in the Santarém region, PA.

Gears (economic life)	<1t	1<4t	4<8t	8<15t	≥15t	Source
Gill net (3 years)	85	135	135	230	230	**
Drift net (3 years)	400	600	600	800	800	*
Long line (1 year)	25	25	25	25	25	**
Purse seine (3 years)	800	800	800	800	800	**
Cast net (1 year)	100	100	100	100	100	**
Line and pole (1 year)	5	5	5	5	5	
Harpoon (1 year)	20	20	20	20	20	**
Canoe (5 years)	150	150	150	150	150	*
N (Landings)	1828	808	114	71	28	

* Based on 50 interviews, see Almeida et al. (in press).
** Prices collected in Santarém market, 1998.

Table 2. Estimates of OLS production function.

	M1	**M2**
Intersept	3.011	3.231
LN R$Capital	0.118	0.116
LN R$Ice Cost	0.446	0.412
LN R$Fuel Cost	0.130	0.112
LN Labor	0.344	0.362
River Level	-0.075	-0.077
Dummy Market	-0.267	
Dummy Gear	**-0.101**	
R-Squared	0.61	0.61
R-squared ajusted	0.61	0.60
Sum of Coefficients	1.04	1.00
F Value	643.97	871.21

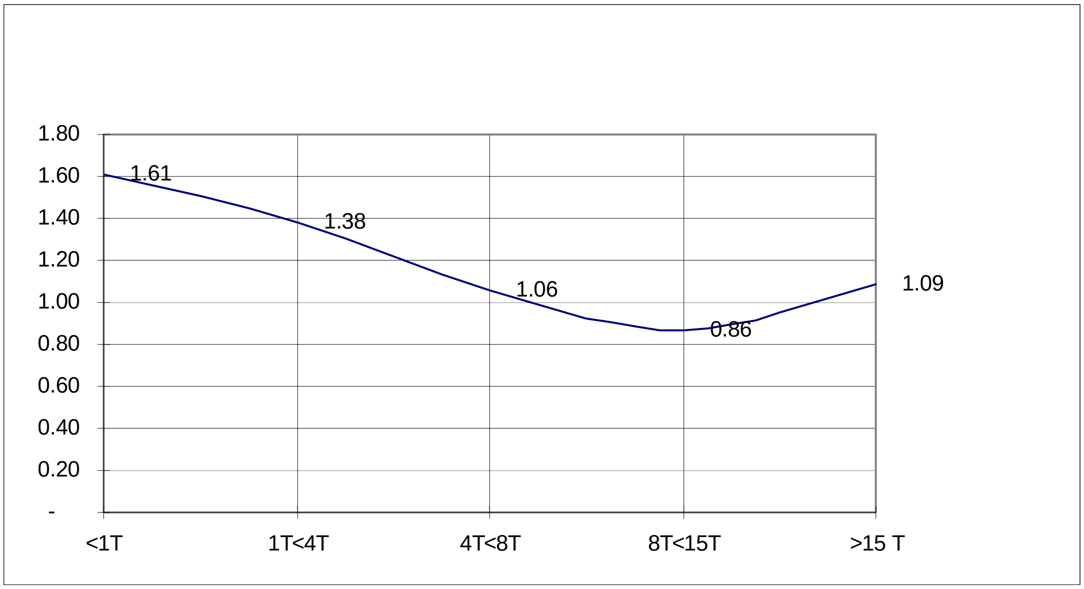
Bold: pvalue <0.05
All other: Pvalue<0.01

Table 3. Catch per fisheman per day (CPUE) by type of gear and size class boat, Santarém, 1997.

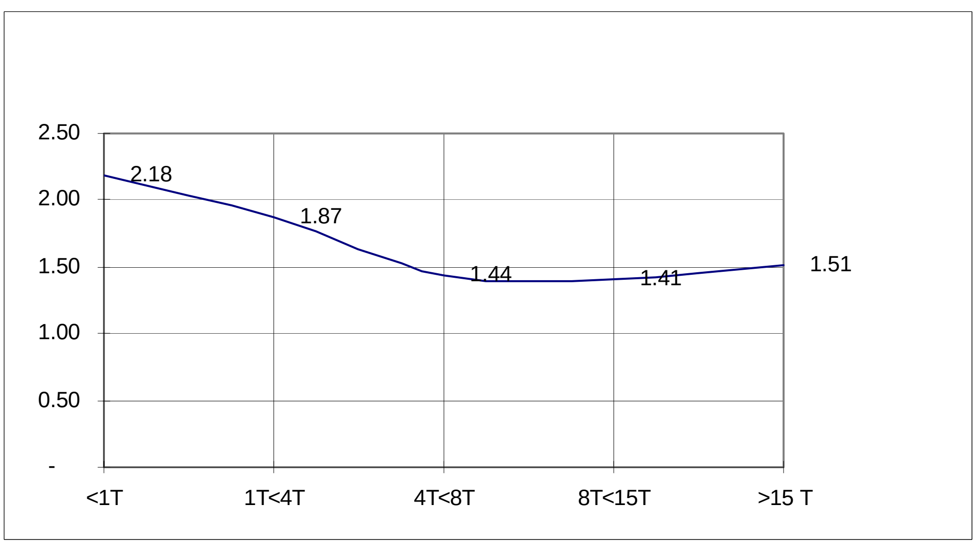
	<1T	1T<4T	4T<8T	8T<15T	≥15 T	Average
Hapoon	12.02				4.26	10.73
Drift Net	15.15	15.47	13.97	17.10	16.65	15.81
Pole and hook	5.54				3.06	5.40
Long Line	9.91	13.47			12.07	10.38
Hand Line and hook	2.85					2.85
Gillnet	11.58	24.26	7.63		13.31	12.18
Gillnet (nylon)	13.42	36.23	37.64	50.05	25.37	22.75
Purse net		24.40	68.44	63.13	35.73	46.60
Cast net	19.17				12.83	18.80
Average	12.18	26.42	34.10	49.53	17.55	15.16

Figure 1- Marginal Revenue Product of capital, ice, fuel and Marginal Physical Product of Labor per boat class, Santarém, 1997.

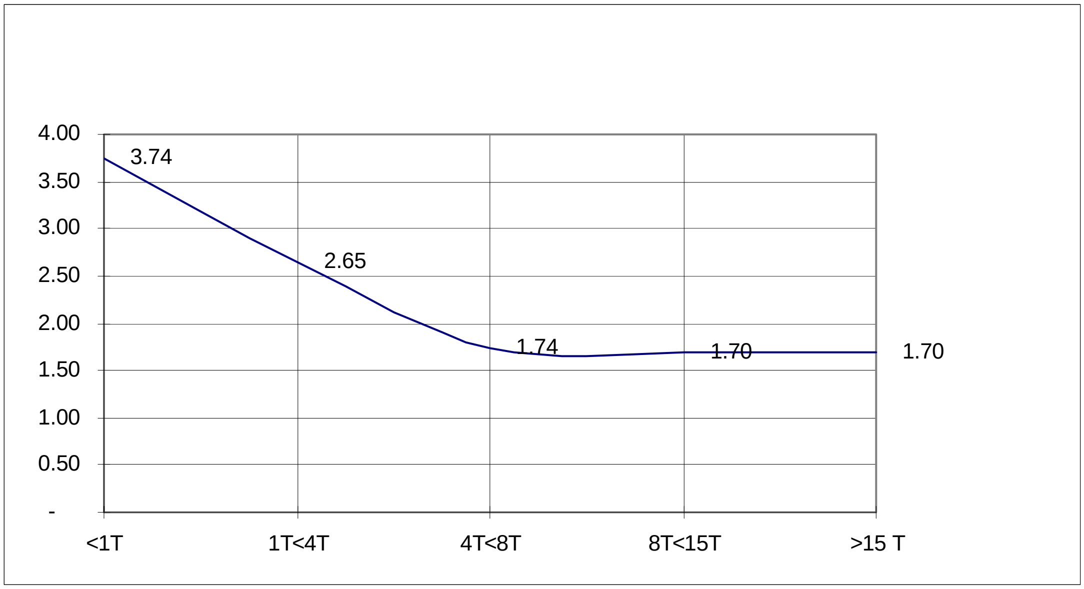
Marginal Revenue Product (Capital)



Marginal Revenue Product (Fuel)



Marginal Revenue Product (Ice)



Marginal Physical Product (Labor)