# JIMAR ANNUAL REPORT FOR FY 2001 (Project 653540)

**P.I. Name:** PingSun Leung, Khem Sharma and Sam Pooley
**Project Research Assistant:** Naresh Pradhan

**Project Title:** Analyzing the Technical and Economic Structure of Hawaii's Pelagic Fishery

**Funding Agency:** NOAA/NMFS/Pelagic Fisheries Research Program

Project start date: October 1, 1999

## 1. Purpose of Project

The main objective of this study is to determine the technological and economic interrelationships in Hawaii-based longline, troll, and handline pelagic fisheries using a multi-product dual revenue function approach. A secondary objective is to provide a preliminary test of incorporating these estimated relations into the existing allocation model. The specific objectives of the project include:

1. Compile existing secondary trip-level information on revenue, landings and prices by species as well as other trip characteristics, including trip lengths, and target for Hawaii-based longline, troll, and handline pelagic fisheries contained in NMFS logbook and HDAR (Hawaii Division of Aquatic Resources) catch records;
2. Conceptualize and specify multi-product dual revenue function models for longline and nonlongline commercial (troll/handline) fisheries and develop their estimation procedures;
3. Test for input-output separability and nonjointness-in-inputs of the harvesting technology of Hawaii-based longline, troll, and handline pelagic fisheries;
4. Estimate own and cross-price supply and effort elasticities;
5. Estimate the multi-species economies of scope, species-specific economies of scale, multi-species economies of scale, species-specific marginal costs and cost elasticities;
6. Assess the impact of area-closure by conducting separate analyses of the data collected before and after the implementation of area-closure regime and comparing the estimates for the two periods; and
7. Incorporate the estimated relations into the existing mathematical programming allocation model as a demonstration on how the estimated relations can be used.

## 2. Progress During FY 2001 (July 1, 2000 to June 30, 2001)

Most of project work during FY 2000 was related to collection, compilation and organization of necessary data for the longline fleet. Work during FY 2001 is concerned with descriptive data analyses and the specification and estimation of the revenue function model for the longline fishery. The descriptive results include the contributions of individual species to total marketed landings and ex-vessel revenues and time trends of ex-vessel prices of major longline species. Information on contributions of each species to total landings and revenues was used in determining the number of species or species groups in the revenue function. The estimation of output supply functions and related price and effort elasticities for the longline fishery has been completed. These tasks and related results are highlighted below.

The HDAR data for the non-longline commercial pelagic fisheries are also compiled in FY 2001. These include troll, handline, and aku boats. Since aku boats harvest primarily aku and one or two other minor species, they are not considered in revenue function analyses. Unlike the longline fishery, effort (trip length, number of hooks) and vessel-specific (tonnage, size, etc.) information do not exist for the nonlongline fleets. This problem is being overcome by aggregating the trip level data to both monthly and quarterly levels and defining effort in terms of number of trips per month or quarter. The descriptive analyses as well as the specification and estimation of the revenue function models for troll and handline fisheries are in progress.

*2.1 Pounds Sold and Ex-Vessel Revenues*

Total annual pounds sold and their species composition for each trip type (swordfish, mixed and tuna) as well as for entire longline trips during 1991 to 1998 are presented in Appendix Table 1. Total ex-vessel revenues and revenue shares by species are presented in Appendix Table 2. Note that total pounds sold and total revenues presented here correspond to the matched observations only (i.e., 6,666 or 77% of HDAR total observations) and hence can be different from those found in longline annual reports.

For trips targeting swordfish, as expected, swordfish is the dominant species, accounting for about 80% each of total pounds sold and total revenue. Bigeye is the second important species for swordfish trips. For mixed trips, swordfish is dominant, followed by bigeye tuna and yellowfin tuna, and for tuna trips bigeye is dominant, followed by yellowfin and albacore. Comparing over time, the importance of swordfish has declined while that of bigeye tuna has increased. For example, based on matched observations, the contribution of swordfish to total longline revenue has decreased from 52% in 1991 to 23% in 1998, while the contribution of bigeye tuna has increased from 28% to 49%.

*2.2 Ex-vessel prices*

The mean annual prices for the major longline species are presented in Appendix Table 3. On the average, prices have been fairly stable during 1991 to 1998, especially for the major species targeted by longliners (bigeye tuna, broadbill swordfish and yellowfin tuna). This suggests that although species composition has changed substantially in recent years, relative prices have remained fairly stable. However, as indicated by the standard deviations, variations in prices within a year are considerable. Comparing among the species, bigeye tuna fetched consistently the highest price, followed by swordfish and yellowfin tuna. In general, albacore tuna fetched the lowest price.

*2.3 Revenue function specification*

Based on pound and revenue shares, prices and biological characteristics, for the revenue function analysis, various longline species are aggregated to six (6) species or species groups. These include yellowfin tuna (Y), albacore (A), bigeye tuna (T), broadbill swordfish (B), marlin (M) and other pelagic species (O). Marlin (M) is an aggregate of black marlin, blue marlin and stripped marlin. Similarly, other pelagic species include various shark species (mako, thresher, tiger, and other sharks) and other pelagic species (aku, barracuda, bluefin tuna, mahimahi, monchong, ono, opah, papio, sailfish, short nose, walu and other unclassified pelagics).

Various vessel-specific (vessel length, horsepower, gross registered tonnage and net tonnage) and trip-level inputs (trip length, and number of hooks and number of sets) were considered in deriving a measure of composite input/effort in the revenue function. Based on the correlation results of these variables, trip length and vessel net tonnage were selected in order to compute the composite effort. A single composite input (Z) is derived as the product of trip length (in days) and vessel net tonnage.

The revenue function was specified to be of both Leontief's form and the translog form. Although the Leontief's form is more popular in previous studies, we had proposed the translog form in this study. Accordingly, both forms were tried. However, based on preliminary results the Leontief's form was found to be superior to the translog form. Perhaps, this may be due to the restriction that revenue shares in the latter should need to add up to one. For this reason, the Leontief's revenue function is chosen in this study. Mathematical details underlying the Leontief's revenue function, derivation of output supply functions to be estimated and formulae involved in calculating various elasticities are given in Appendix 4.

For part of 1991 information on bigeye tuna was missing in the HDAR longline data. It is suspected that bigeye may have been included with one of the other tuna species. Because of this, the 1991 data are excluded in revenue function analysis.

### *2.4 Estimation Procedures*

As mentioned above, different species harvested by longliners have been aggregated to six species or species groups. The problem is that all vessels do not land all species in every trip. This resulted in missing information on outputs and prices for a sizeable proportion of the observations. For example, of the 6,666 matched trip-level observations 2,293 or 34% had complete output and price information. For estimating the output supply functions, the data need to have complete information on outputs and prices of all species included in the model. For this reason, the observations with no information on any of the output or price variables were excluded.

In view of differences in harvesting technologies and output composition among different trip types, revenue function analyses have been carried out separately for swordfish, mixed and tuna trips. This will provide information on how different trip types respond to changes in prices and fishing effort. For comparison purpose, analysis has also been conducted on all trip types combined.

The estimation procedure is driven by two assumptions. First, we assume that the fisherman's decision to harvest a given quantity of a particular fish species is influenced by the level of current price he/she gets for that species. Second, we assume that fishermen base their decisions on some kind of expected prices rather than on the current prices. Accordingly three different types of revenue functions are specified. The first one relates the current trip-level outputs to current trip-level prices for each vessel. In the second model, current trip-level outputs are expressed as functions of prices obtained in the immediate preceding trip. In the third model, the trip-level data are aggregated to the quarterly level and total quarterly outputs are related to their average prices in that quarter. The second and third models are the models based on expected prices. These models would also avoid the possible simultaneity problem in using current outputs and current prices.

The systems of output supply functions obtained from the generalized Leontief's revenue functions for different trip types and for different assumptions for output and price relationships are estimated using Zellner's seemingly unrelated regression estimation (SURE) technique. Under the SURE framework the cross-price coefficients are symmetric. Besides the parameter estimates for the systems output supply functions, assumptions of nonjointness-in-inputs and input-output separability are also tested. Finally, own-price, cross-price and effort elasticities of output supply functions for six species are computed. These results are summarized next.

### *2.5 Results*

The three models estimated (trip-level current price, trip-level lagged price and quarterly) were quite similar in terms of sign, magnitude and significance level of estimates for own-price, cross-price, and effort elasticities. Furthermore, the models were also generally in agreements with respect to tests of hypotheses for nonjointness in inputs and input-output separability. However, in terms of behavioral assumptions, the results obtained from the second model (i.e. fishermen responding to the prices received in the previous trip rather than what they would receive in the current trip) seem more plausible. Hence, the results summarized here pertain to the model with current trip-level outputs with lagged prices. The variables (outputs, prices and effort) involved in estimating the lagged model are summarized in Appendix Table 5.

#### *2.5.1 Parameter Estimates*

The parameter estimates for the supply functions are presented in Appendix Table 6. Own-price and cross-price elasticities presented in Section 2.5.3 are estimated based on the estimated coefficients of supply equations. A number of estimated coefficients in most supply equations were significant at the 0.05 level. Of particular interest are the effort and squared effort coefficients. Effort coefficients are positive in most of the supply equations and also significant in supply equations of major species targeted under each trip type. The coefficients for squared effort are mostly negative, indicating that effort is characterized by diminishing marginal productivity. However, the magnitude of the squared effort coefficients implies that changes in marginal productivity would be negligible.

*2.5.2 Tests of hypotheses*

The results of the tests of hypotheses for nonjointness in inputs and input-output separability are presented in Appendix Table 7. The results rejected both null hypotheses for all trip types as well as all trips combined. The rejection of nonjointness in production suggests that there are technical interactions among species targeted by longliners, and single species management would affect the exploitation of other species. Similarly, the rejection of separability between inputs and outputs suggests that management of the biomass or the aggregate stock of species is also inappropriate.

*2.5.3 Elasticities estimates*

The estimated own-price, cross-price, effort elasticities of output supply functions, along with the standard errors are presented in Appendix Table 8. Elasticities and their standard errors are calculated at the observed mean values of variables involved.

The theory suggests that own-price supply elasticities be positive, but cross-price elasticities can be positive or negative. As shown in Appendix Table 8, a number of own-price elasticities for each trip type are negative. However, except for other pelagic species for tuna trips, none of these negative own-price elasticities are significant. More interestingly, none of the positive own-price supply elasticities is significant. Own-price elasticities obtained from the other two models (current trip and quarterly) were also not significant. Thus, these results suggest that output supply decisions of longliners are independent of prices they get.

As shown in Appendix Table 8, a number of cross-price elasticities are significant at the 0.05 level. The cross-price elasticities between the major targeted species are negative and significant in a number of cases. For example, for the swordfish trips swordfish cross-price elasticities with respect to yellowfin tuna and bigeye tuna are both negative and significant, indicating substitution in production. However, yellowfin and bigeye cross-price elasticities with respect to swordfish are higher than swordfish cross-price elasticities with respect to yellowfin and tuna, indicating an increase in swordfish price would reduce the outputs of yellowfin and bigeye more than decrease of swordfish output due to increase in yellowfin and bigeye prices. In mixed trips, bigeye tuna and yellowfin tuna are found be significant substitutes. However, the effect of a change in bigeye price on yellowfin output is much larger compared to the effect of yellowfin on bigeye. For tuna trips, bigeye is found to be a significant substitute for both swordfish and yellowfin tuna. The bigeye's relationship with yellowfin tuna in tuna trips is similar to that in the mixed trips, while this relationship with swordfish is opposite of that found in the swordfish trips.

Among the remainder of the species, cross-price elasticities between albacore and other pelagics are always positive, indicating their complementary relationships in production. On the other hand, bigeye tuna and marlin cross-price elasticities with respect to other pelagic species are always negative.

Therefore, the results suggest that although the outputs are not responsive to their own-prices, there exist economic and technological relationships among various species harvested by longliners. Thus neither the single species management nor treating all species as one aggregate stock will be appropriate in managing the longline fishery.

*2.6 Discussion*

The objective of examining the effect of area closure on interrelationships among species could not be completed owing to limited sample size. Because of having to exclude the observations with missing information, there were not enough observations to estimate the model separately for before and after the area closure.

**3. Work Plan for the Next Fiscal Year (July 1, 2001 to June 30, 2002)**

1. Identify and estimate variables (such as fishing effort and the number of species) and estimate the revenue function model for troll and handline fisheries;
2. Test for input-output separability and nonjointness-in-inputs of the harvesting technology of Hawaii-based troll and handline pelagic fisheries;
3. Estimate own and cross-price supply and effort elasticities for troll and handline fisheries;
4. Estimate the multi-species economies of scope, species-specific economies of scale, multi-species economies of scale, species-specific marginal costs and cost elasticities;
5. Incorporate the estimated relations into the existing mathematical programming allocation model as a demonstration on how the estimated relations can be used; and
6. Report write-up, including preparation of one or two articles for journals and international conferences.

**4. List of papers published in refereed journals during FY 2001.**

None

**5. Other papers, technical reports, meeting presentations, etc.**

None

**6. Names of students graduating with MS or Ph.D degrees during FY 2001. Include title of thesis or dissertation.**

None

**7. For multi-year projects, provide budget for the next year on a separate page.**

# Appendix
## Table 1. Species Composition of Pounds Sold by Hawaii's Longline Fishery, 1991 - 1998

| | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 |
|---|---|---|---|---|---|---|---|---|
| Swordfish trips (n = 1,225) | | | | | | | | |
| Total pounds sold ('000) | 4,659 | 5,220 | 6,503 | 3,854 | 1,337 | 889 | 1,140 | 1,428 |
| Species shares (%) | | | | | | | | |
| Yellowfin tuna | 3.9 | 2.1 | 3.6 | 3.4 | 5.2 | 4.2 | 9.2 | 3.3 |
| Albacore tuna | 2.1 | 2.9 | 3.0 | 5.2 | 2.8 | 5.0 | 3.2 | 2.2 |
| Bigeye tuna | 3.7 | 6.0 | 9.5 | 6.3 | 8.4 | 6.2 | 9.5 | 8.8 |
| Broadbill swordfish | 80.1 | 83.1 | 78.2 | 78.6 | 78.3 | 78.9 | 68.9 | 81.4 |
| Marlin | 3.3 | 3.3 | 3.8 | 4.4 | 2.9 | 3.6 | 4.4 | 2.8 |
| Other pelagics | 6.9 | 2.5 | 1.9 | 2.1 | 2.3 | 2.0 | 4.8 | 1.5 |
| Mixed trips (n = 2,205) | | | | | | | | |
| Total pounds sold ('000) | 5,386 | 5,578 | 4,891 | 1,574 | 2,202 | 1,965 | 2,288 | 2,987 |
| Species composition (%) | | | | | | | | |
| Yellowfin tuna | 14.3 | 7.2 | 7.1 | 20.9 | 17.7 | 13.8 | 16.5 | 7.3 |
| Albacore tuna | 3.1 | 4.3 | 3.5 | 1.9 | 2.7 | 5.8 | 3.1 | 3.5 |
| Bigeye tuna | 10.2 | 17.7 | 24.0 | 28.6 | 21.4 | 16.9 | 11.4 | 21.1 |
| Broadbill swordfish | 40.3 | 55.1 | 56.3 | 31.5 | 42.4 | 48.0 | 56.0 | 55.1 |
| Marlin | 14.6 | 8.5 | 6.9 | 12.3 | 10.1 | 10.0 | 8.6 | 8.3 |
| Other pelagics | 17.5 | 7.3 | 2.3 | 4.8 | 5.7 | 5.5 | 4.4 | 4.7 |
| Tuna trips (n = 3,236) | | | | | | | | |
| Total pounds sold ('000) | 2,735 | 2,976 | 4,513 | 4,308 | 4,912 | 5,026 | 8,163 | 9,221 |
| Species composition (%) | | | | | | | | |
| Yellowfin tuna | 8.3 | 5.6 | 12.4 | 11.0 | 12.4 | 9.8 | 11.4 | 9.4 |
| Albacore tuna | 8.2 | 6.2 | 8.7 | 9.9 | 18.5 | 22.7 | 27.8 | 17.8 |
| Bigeye tuna | 16.7 | 43.2 | 40.8 | 48.0 | 33.7 | 34.9 | 34.8 | 45.7 |
| Broadbill swordfish | 4.1 | 3.3 | 2.4 | 0.8 | 1.8 | 2.1 | 1.4 | 2.5 |
| Marlin | 20.4 | 22.5 | 18.1 | 12.4 | 16.3 | 13.7 | 8.9 | 8.1 |
| Other pelagics | 42.4 | 19.2 | 17.8 | 17.8 | 17.3 | 16.8 | 15.7 | 16.4 |
| All trips (n = 6,666) | | | | | | | | |
| Total pounds sold ('000) | 12,780 | 13,774 | 15,907 | 9,735 | 8,451 | 7,880 | 11,591 | 13,636 |
| Species composition (%) | | | | | | | | |
| Yellowfin tuna | 9.2 | 4.9 | 7.2 | 9.6 | 12.7 | 10.2 | 12.2 | 8.3 |
| Albacore tuna | 3.8 | 4.2 | 4.8 | 6.8 | 11.9 | 16.5 | 20.5 | 13.1 |
| Bigeye tuna | 9.2 | 18.8 | 22.8 | 28.4 | 26.5 | 27.1 | 27.7 | 36.5 |
| Broadbill swordfish | 47.0 | 54.5 | 49.9 | 36.6 | 24.5 | 22.2 | 18.8 | 22.3 |
| Marlin | 11.7 | 9.5 | 8.8 | 9.2 | 12.5 | 11.7 | 8.4 | 7.6 |
| Other pelagics | 19.0 | 8.0 | 6.5 | 9.5 | 11.9 | 12.3 | 12.4 | 12.3 |

n denotes the number of matched observations from NMFS logbook and HDAR sales data.

**Table 2. Revenue Shares of Hawaii's Longline Fishery by Species, 1991 - 1998**

| | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 |
|---|---|---|---|---|---|---|---|---|
| Swordfish trips (n = 1,225) | | | | | | | | |
| Total revenue ($1,000) | 12,788 | 15,123 | 19,329 | 12,686 | 4,416 | 2,798 | 3,089 | 3,223 |
| Species shares (%) | | | | | | | | |
| Yellowfin tuna | 4.3 | 2.1 | 3.3 | 3.3 | 5.1 | 5.0 | 8.6 | 3.9 |
| Albacore tuna | 0.9 | 0.6 | 0.8 | 1.0 | 0.6 | 1.3 | 1.3 | 1.1 |
| Bigeye tuna | 11.0 | 9.5 | 12.0 | 10.0 | 9.0 | 12.0 | 11.4 | 10.5 |
| Broadbill swordfish | 81.6 | 85.6 | 81.2 | 81.7 | 82.4 | 76.4 | 74.9 | 81.3 |
| Marlin | 1.1 | 1.2 | 1.3 | 1.9 | 1.2 | 1.5 | 1.7 | 1.8 |
| Other pelagics | 1.0 | 1.0 | 1.4 | 2.1 | 1.6 | 3.9 | 2.2 | 1.4 |
| Mixed trips (n = 2,205) | | | | | | | | |
| Total revenue ($1,000) | 14,430 | 15,064 | 13,844 | 4,976 | 6,051 | 5,975 | 6,364 | 6,666 |
| Species shares (%) | | | | | | | | |
| Yellowfin tuna | 14.0 | 8.6 | 7.1 | 19.7 | 16.4 | 14.3 | 14.9 | 8.5 |
| Albacore tuna | 1.4 | 1.7 | 1.3 | 0.6 | 1.1 | 2.5 | 1.4 | 2.0 |
| Bigeye tuna | 29.5 | 24.9 | 30.3 | 37.5 | 26.4 | 22.1 | 15.4 | 26.8 |
| Broadbill swordfish | 46.8 | 57.4 | 57.5 | 34.3 | 49.3 | 52.8 | 62.6 | 55.1 |
| Marlin | 4.7 | 4.0 | 2.5 | 5.5 | 3.2 | 4.0 | 2.9 | 4.4 |
| Other pelagics | 3.5 | 3.5 | 1.3 | 2.3 | 3.6 | 4.3 | 2.8 | 3.2 |
| Tuna trips (n = 3,236) | | | | | | | | |
| Total revenue ($1,000) | 6,377 | 7,267 | 10,461 | 11,483 | 10,064 | 11,389 | 16,924 | 19,714 |
| Species shares (%) | | | | | | | | |
| Yellowfin tuna | 10.4 | 6.9 | 14.4 | 10.8 | 16.6 | 12.4 | 14.9 | 10.6 |
| Albacore tuna | 5.2 | 3.9 | 5.3 | 5.1 | 9.3 | 13.3 | 16.3 | 10.6 |
| Bigeye tuna | 58.1 | 62.4 | 59.4 | 67.1 | 54.9 | 54.3 | 52.5 | 62.6 |
| Broadbill swordfish | 5.4 | 3.8 | 3.2 | 1.2 | 3.1 | 3.5 | 2.0 | 2.6 |
| Marlin | 9.7 | 12.1 | 8.5 | 7.2 | 6.9 | 7.3 | 5.0 | 4.5 |
| Other pelagics | 11.3 | 10.9 | 9.2 | 8.6 | 9.2 | 9.3 | 9.3 | 9.1 |
| All trips (n = 6,666) | | | | | | | | |
| Total revenue ($1,000) | 33,594 | 37,454 | 43,634 | 29,145 | 20,531 | 20,163 | 26,377 | 29,603 |
| Species shares (%) | | | | | | | | |
| Yellowfin tuna | 9.7 | 5.6 | 7.2 | 9.0 | 14.1 | 11.9 | 14.2 | 9.4 |
| Albacore tuna | 1.9 | 1.7 | 2.0 | 2.5 | 5.0 | 8.4 | 10.9 | 7.6 |
| Bigeye tuna | 27.9 | 26.0 | 29.2 | 37.2 | 36.6 | 38.9 | 38.7 | 48.9 |
| Broadbill swordfish | 52.2 | 58.4 | 55.0 | 41.9 | 33.8 | 28.2 | 25.2 | 23.0 |
| Marlin | 4.3 | 4.4 | 3.4 | 4.6 | 4.6 | 5.5 | 4.1 | 4.2 |
| Other pelagics | 4.0 | 3.9 | 3.2 | 4.7 | 6.0 | 7.0 | 6.9 | 6.9 |

n denotes the number of matched observations from NMFS logbook and HDAR sales data.

**Appendix Table 3. Summary Statistics of Ex-vessel Prices for Longline Fishery by Species, 1991-1998**

| | | Swordfish Trips | | Mixed Trips | | Tuna Trips | | All Trips | |
|---|---|---|---|---|---|---|---|---|---|
| Species | Year | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. |
| Yellowfin tuna | 1991 | 3.43 | 2.16 | 3.02 | 1.11 | 3.08 | 1.10 | 3.11 | 1.37 |
| | 1992 | 2.87 | 1.31 | 3.33 | 1.41 | 2.79 | 1.15 | 3.07 | 1.33 |
| | 1993 | 2.74 | 1.04 | 2.90 | 1.33 | 2.81 | 0.99 | 2.82 | 1.12 |
| | 1994 | 3.27 | 1.50 | 3.06 | 1.07 | 3.16 | 1.49 | 3.16 | 1.40 |
| | 1995 | 3.33 | 1.31 | 2.79 | 1.31 | 2.74 | 0.96 | 2.81 | 1.11 |
| | 1996 | 3.23 | 1.45 | 3.26 | 1.34 | 3.00 | 1.18 | 3.09 | 1.25 |
| | 1997 | 2.81 | 1.13 | 3.04 | 1.38 | 2.87 | 0.89 | 2.90 | 1.02 |
| | 1998 | 2.63 | 1.14 | 2.74 | 1.08 | 2.72 | 1.06 | 2.72 | 1.07 |
| Albacore | 1991 | 1.43 | 0.81 | 1.41 | 0.57 | 1.65 | 0.63 | 1.49 | 0.65 |
| | 1992 | 0.89 | 0.57 | 1.32 | 0.70 | 1.67 | 0.64 | 1.32 | 0.71 |
| | 1993 | 0.92 | 0.58 | 1.15 | 0.68 | 1.55 | 0.53 | 1.26 | 0.65 |
| | 1994 | 1.00 | 0.67 | 1.18 | 0.61 | 1.58 | 0.76 | 1.36 | 0.75 |
| | 1995 | 0.93 | 0.48 | 1.11 | 0.76 | 1.34 | 0.66 | 1.25 | 0.69 |
| | 1996 | 0.89 | 0.42 | 1.24 | 0.44 | 1.47 | 0.55 | 1.37 | 0.54 |
| | 1997 | 1.14 | 1.09 | 1.14 | 0.49 | 1.44 | 0.56 | 1.37 | 0.61 |
| | 1998 | 1.12 | 0.55 | 1.19 | 0.49 | 1.33 | 0.51 | 1.29 | 0.51 |
| Bigeye tuna | 1991 | 3.48 | 2.16 | 3.90 | 1.95 | 3.70 | 1.63 | 3.77 | 1.88 |
| | 1992 | 4.54 | 2.77 | 4.04 | 2.35 | 3.58 | 1.27 | 3.99 | 2.17 |
| | 1993 | 3.76 | 2.35 | 4.06 | 2.44 | 3.45 | 1.12 | 3.73 | 1.99 |
| | 1994 | 4.84 | 3.09 | 4.27 | 2.38 | 3.99 | 1.49 | 4.28 | 2.24 |
| | 1995 | 4.11 | 2.21 | 3.19 | 1.57 | 3.38 | 1.60 | 3.41 | 1.68 |
| | 1996 | 5.06 | 3.06 | 4.37 | 2.18 | 3.58 | 1.29 | 3.92 | 1.83 |
| | 1997 | 3.45 | 1.54 | 3.77 | 2.18 | 3.13 | 0.95 | 3.28 | 1.36 |
| | 1998 | 2.92 | 1.24 | 3.02 | 1.34 | 3.08 | 1.00 | 3.06 | 1.11 |
| Swordfish | 1991 | 2.82 | 0.86 | 2.98 | 1.10 | 2.23 | 1.24 | 2.81 | 1.11 |
| | 1992 | 3.19 | 0.88 | 2.88 | 0.88 | 2.37 | 1.37 | 2.87 | 1.02 |
| | 1993 | 3.21 | 0.66 | 2.96 | 0.80 | 2.48 | 1.27 | 2.96 | 0.91 |
| | 1994 | 3.47 | 0.93 | 3.50 | 1.00 | 3.05 | 1.63 | 3.37 | 1.19 |
| | 1995 | 3.42 | 0.77 | 3.13 | 0.79 | 3.10 | 1.39 | 3.17 | 1.07 |
| | 1996 | 3.24 | 0.86 | 3.21 | 0.98 | 3.24 | 1.53 | 3.23 | 1.23 |
| | 1997 | 2.88 | 1.03 | 3.10 | 0.95 | 3.11 | 1.51 | 3.07 | 1.23 |
| | 1998 | 2.22 | 0.77 | 2.31 | 0.93 | 2.17 | 1.27 | 2.23 | 1.10 |
| Marlin | 1991 | 1.27 | 0.72 | 1.06 | 0.62 | 1.19 | 0.59 | 1.13 | 0.64 |
| | 1992 | 1.40 | 0.82 | 1.57 | 0.76 | 1.47 | 0.65 | 1.50 | 0.74 |
| | 1993 | 1.22 | 0.54 | 1.31 | 0.64 | 1.21 | 0.51 | 1.25 | 0.56 |
| | 1994 | 1.78 | 0.86 | 1.53 | 0.60 | 1.67 | 0.57 | 1.67 | 0.67 |
| | 1995 | 1.68 | 2.05 | 1.15 | 1.00 | 1.01 | 0.56 | 1.12 | 0.96 |
| | 1996 | 1.59 | 0.62 | 1.32 | 0.59 | 1.29 | 0.61 | 1.32 | 0.60 |
| | 1997 | 1.75 | 1.22 | 1.51 | 0.94 | 1.36 | 0.56 | 1.41 | 0.71 |
| | 1998 | 1.83 | 0.81 | 1.55 | 0.77 | 1.43 | 0.64 | 1.48 | 0.69 |
| Other pelagics | 1991 | 0.65 | 0.63 | 0.94 | 0.80 | 0.90 | 0.62 | 0.87 | 0.72 |
| | 1992 | 1.33 | 0.90 | 1.51 | 1.02 | 1.41 | 0.49 | 1.44 | 0.85 |
| | 1993 | 1.77 | 2.39 | 1.50 | 1.70 | 1.29 | 0.51 | 1.47 | 1.55 |
| | 1994 | 2.32 | 3.38 | 1.87 | 2.53 | 1.41 | 0.53 | 1.74 | 2.14 |
| | 1995 | 2.38 | 3.37 | 2.02 | 2.82 | 1.19 | 0.50 | 1.51 | 1.85 |
| | 1996 | 6.88 | 7.59 | 2.84 | 3.36 | 1.39 | 0.63 | 2.22 | 3.18 |
| | 1997 | 2.02 | 3.05 | 3.09 | 4.68 | 1.32 | 0.47 | 1.70 | 2.31 |
| | 1998 | 2.19 | 2.16 | 2.15 | 2.31 | 1.35 | 0.66 | 1.58 | 1.38 |

**Appendix 4. Econometric Model**

The generalized Leontief's revenue function is given as:

$$R(Z, P) = \sum_i \sum_j \beta_{ij} (P_i P_j)^{\frac{1}{2}} Z + \sum_i \beta_i P_i Z^2$$

where R is total revenue accrued from all fish species harvested; Z is the amount of composite effort (input) used, and P is a vector of prices.

According to Hotelling's Lemma, differentiating the revenue function with respect to prices yields a system of output supply functions as:

$$\frac{\partial R(P, Z)}{\partial P_i} = Q_i = \sum_{j \neq i} \beta_{ij} \left(P_j / P_i\right)^{\frac{1}{2}} Z + \beta_{ii} Z + \beta_i Z^2 \text{, i, j = A, T, B, Y, M and O}$$

The symmetry condition requires that $\beta_{ij} = \beta_{ji}$ for $i \neq j$. Separability between inputs and outputs involves the restriction that $\beta_i = 0$ and nonjointness-in-inputs can be examined by testing the restriction that $\beta_{ij} = 0 \ \forall \ i \neq j$.

The estimated supply equations form the basis for computing own-price supply elasticities for each species and cross-price elasticities among the pairs of species. Accordingly, own-price elasticity of the ith fish species ($\varepsilon_i$) could be estimated as follows:

$$\varepsilon_i = \frac{\partial Q_i}{\partial P_i} \cdot \frac{P_i}{Q_i} = -\frac{1}{2Q_i} \left[ \sum_{j \neq i} \beta_{ij} \left(P_j / P_i\right)^{\frac{1}{2}} Z \right]$$

Similarly the cross-price elasticity of the ith species with respect to the jth species ($\varepsilon_{ij}$) could be computed as:

$$\varepsilon_{ij} = \frac{\partial Q_i}{\partial P_j} \cdot \frac{P_j}{Q_i} = \frac{1}{2Q_i} \beta_{ij} \left(P_j / P_i\right)^{\frac{1}{2}} Z$$

Finally, effort elasticity (i.e. supply response to a change in the composite effort) for the ith species ($\varepsilon_{iz}$) could be computed as follows:

$$\frac{\partial Q_i}{\partial Z} \cdot \frac{Z}{Q_i} = \left[ \sum_{j \neq i} \beta_{ij} \left(P_j / P_i\right)^{\frac{1}{2}} + \beta_{ii} + 2\beta_i Z \right] \cdot \frac{Z}{Q_i}$$

Note that elasticities and their standard errors are evaluated at the observed mean values of variables involved.

**Appendix Table 5. Summary Statistics of Variables Involved in Estimating Trip-Level Output Supply Functions with One-period Lagged Prices, 1992-1998**

| | Swordfish Trips (n = 216) | | Mixed Trips (n = 551) | | Tuna Trips (n = 352) | | All Trips (n = 1,119) | |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. |
| Outputs (Pounds/trip) | | | | | | | | |
| Yellowfin tuna | 967 | 1,231 | 1,192 | 1,885 | 1,195 | 1,582 | 1,149 | 1,683 |
| Albacore tuna | 747 | 1,256 | 471 | 793 | 2,097 | 3,646 | 1,035 | 2,305 |
| Bigeye tuna | 1,380 | 1,734 | 2,211 | 2,821 | 3,385 | 3,945 | 2,420 | 3,147 |
| Swordfish | 10,581 | 9,852 | 5,408 | 7,268 | 582 | 2,077 | 4,888 | 7,632 |
| Marlin | 899 | 1,245 | 1,041 | 1,402 | 1,506 | 1,585 | 1,160 | 1,453 |
| Other pelagics | 539 | 726 | 624 | 930 | 1,939 | 1,819 | 1,021 | 1,398 |
| Prices ($/lb) | | | | | | | | |
| Yellowfin tuna | 3.04 | 1.13 | 3.20 | 1.23 | 2.93 | 1.04 | 3.09 | 1.16 |
| Albacore tuna | 0.99 | 0.62 | 1.29 | 0.67 | 1.43 | 0.58 | 1.28 | 0.65 |
| Bigeye tuna | 4.07 | 2.08 | 3.86 | 1.95 | 3.45 | 1.30 | 3.77 | 1.81 |
| Swordfish | 3.24 | 0.92 | 3.03 | 0.95 | 2.91 | 1.36 | 3.04 | 1.10 |
| Marlin | 1.64 | 1.24 | 1.51 | 0.78 | 1.35 | 0.60 | 1.49 | 0.84 |
| Other pelagics | 2.03 | 2.54 | 1.70 | 1.53 | 1.52 | 1.11 | 1.71 | 1.68 |
| Effort | | | | | | | | |
| Net tonnage | 74.6 | 30.3 | 66.9 | 23.6 | 61.7 | 23.5 | 66.8 | 25.4 |
| Trip length (days) | 18.6 | 7.8 | 11.6 | 4.9 | 12.3 | 3.7 | 13.2 | 5.9 |

n denotes the number of observations with complete information.

**Appendix Table 6. Parameter Estimates for Longline Trip-Level Output Supply Functions (with lagged prices)**

| | Intercept | Yellowfin | Albacore | Bigeye | Swordfish | Marlin | Others | Effort | $\text{Effort}^2$ |
|---|---|---|---|---|---|---|---|---|---|
| Swordfish trips | | | | | | | | | |
| Yellowfin | 1,373.20** | | 0.188 | -0.059 | -0.303 | 0.220* | 0.223** | -0.495 | 8.60E-5 |
| | (240.07) | | (0.116) | (0.149) | (0.181) | (0.130) | (0.070) | (0.366) | (7.30E-5) |
| Albacore | 363.62 | | | -0.138 | 0.128 | -0.149 | 0.059 | 0.188 | -6.00E-5 |
| | (241.47) | | | (0.087) | (0.111) | (0.101) | (0.055) | (0.360) | (7.40E-5) |
| Bigeye | 799.33** | | | | -0.635** | -0.045 | -0.102* | 1.292** | -3.00E-5 |
| | (325.70) | | | | (0.280) | (0.118) | (0.062) | (0.490) | (9.90E-5) |
| Swordfish | 6,342.03** | | | | | 0.070 | -0.156 | 4.934** | -4.90E-4 |
| | (1,883.07) | | | | | (0.142) | (0.086) | (2.389) | (5.73E-4) |
| Marlin | 950.92** | | | | | | -0.024 | -0.246 | 4.67E-7 |
| | (244.49) | | | | | | (0.059) | (0.359) | (7.50E-5) |
| Others | 577.56** | | | | | | | -0.067 | 5.40E-5 |
| | (141.37) | | | | | | | (0.189) | (4.30E-5) |
| Mixed trips | | | | | | | | | |
| Yellowfin | 945.70** | | -0.122 | -0.476* | 0.448 | -0.119 | 0.247** | 0.538 | -1.60E-4 |
| | (215.80) | | (0.093) | (0.250) | (0.315) | (0.178) | (0.111) | (0.535) | (1.43E-4) |
| Albacore | 375.91** | | | 0.136** | -0.029 | -0.119 | 0.070 | 0.180 | -1.80E-6 |
| | (91.33) | | | (0.067) | (0.081) | (0.100) | (0.071) | (0.210) | (6.10E-5) |
| Bigeye | 1,184.79** | | | | 0.276 | -0.232* | -0.260** | 2.290** | -4.90E-4** |
| | (320.33) | | | | (0.383) | (0.132) | (0.086) | (0.715) | (2.12E-4) |
| Swordfish | 2,412.74** | | | | | 0.748** | 0.030 | 3.030* | -5.50E-4 |
| | (808.41) | | | | | (0.167) | (0.105) | (1.593) | (5.35E-4) |
| Marlin | 608.01** | | | | | | -0.006 | 0.351 | -2.40E-4** |
| | (158.35) | | | | | | (0.096) | (0.333) | (1.06E-4) |
| Others | 384.66** | | | | | | | 0.346 | -9.00E-5 |
| | (105.47) | | | | | | | (0.218) | (7.00E-5) |
| Tuna trips | | | | | | | | | |
| Yellowfin | 982.81** | | 0.211 | -1.538 | 0.363 | 0.338 | 0.258 | 1.453* | -4.10E-4 |
| | (301.99) | | (0.458) | (0.436) | (0.253) | (0.277) | (0.266) | (0.890) | (3.86E-4) |
| Albacore | 400.47 | | | -0.427 | 0.362 | 0.333 | 0.006 | 3.598* | -1.93E-3** |
| | (693.47) | | | (0.590) | (0.373) | (0.380) | (0.355) | (1.894) | (8.86E-4) |
| Bigeye | 1,389.05* | | | | -0.688* | 0.105 | -0.168 | 6.728** | -1.77E-3* |
| | (745.81) | | | | (0.358) | (0.281) | (0.330) | (1.950) | (9.51E-4) |
| Swordfish | -229.64 | | | | | 0.025 | 0.706** | 1.048 | -4.60E-4 |
| | (370.34) | | | | | (0.192) | (0.208) | (0.921) | (4.72E-4) |
| Marlin | 1,176.57** | | | | | | -0.090 | -0.659 | 8.80E-5 |
| | (302.49) | | | | | | (0.232) | (0.832) | (3.88E-4) |
| Others | 1,452.24** | | | | | | | -0.590 | 1.63E-4 |
| | (339.85) | | | | | | | (0.886) | (4.35E-4) |
| All trips | | | | | | | | | |
| Yellowfin | 1,144.72** | | -0.186 | -0.290* | 0.062 | 0.167 | 0.193** | 0.212 | -6.00E-5 |
| | (129.55) | | (0.129) | (0.152) | (0.159) | (0.108) | (0.083) | (0.278) | (6.10E-5) |
| Albacore | 698.17** | | | -0.054 | 0.161 | -0.069 | 0.207** | 0.597* | -1.90E-4** |
| | (177.30) | | | (0.109) | (0.128) | (0.103) | (0.077) | (0.324) | (8.40E-5) |
| Bigeye | 1,677.82** | | | | -0.679** | -0.057 | -0.160** | 2.430** | -3.70E-4** |
| | (241.06) | | | | (0.266) | (0.092) | (0.076) | (0.473) | (1.12E-4) |
| Swordfish | 1,739.99** | | | | | 0.198* | -0.078 | 3.854** | 4.60E-5 |
| | (551.82) | | | | | (0.100) | (0.092) | (0.959) | (2.55E-4) |
| Marlin | 870.61** | | | | | | -0.050 | 0.198 | -1.60E-4** |
| | (110.87) | | | | | | (0.061) | (0.221) | (5.20E-5) |
| Others | 782.21** | | | | | | | 0.387** | -1.20E-4** |
| | (105.96) | | | | | | | (0.188) | (5.00E-5) |

** = Statistically significant at the 0.05 level. * = Statistically significant at the 0.10 level.

**Appendix Table 7. Tests Of Hypotheses of Nonjointness in Inputs and Separability Between Inputs and Outputs (trip level with lagged prices)**

| | F Value | | | Decision |
|---|---|---|---|---|
| | Test Statistic | Degrees of Freedom | Critical Value ($\alpha$ = 0.05) | |
| Swordfish trips | | | | |
| Nonjointness in inputs ($\beta_{ij} = 0\ \forall\ i \neq j$) | 2.49 | 15;1,263 | 1.83 | Reject null |
| Input-output separability ($\beta_i = 0$) | 2.83 | 6;1,263 | 2.17 | Reject null |
| Mixed trips | | | | |
| Nonjointness in inputs ($\beta_{ij} = 0\ \forall\ i \neq j$) | 3.12 | 15;3,273 | 1.83 | Reject null |
| Input-output separability ($\beta_i = 0$) | 2.96 | 6;3,273 | 2.17 | Reject null |
| Tuna trips | | | | |
| Nonjointness in inputs ($\beta_{ij} = 0\ \forall\ i \neq j$) | 2.63 | 15;2,079 | 1.83 | Reject null |
| Input-output separability ($\beta_i = 0$) | 3.79 | 6;2,079 | 2.17 | Reject null |
| All trips | | | | |
| Nonjointness in inputs ($\beta_{ij} = 0\ \forall\ i \neq j$) | 3.10 | 15; 6,681 | 1.83 | Reject null |
| Input-output separability ($\beta_i = 0$) | 8.44 | 6; 6,681 | 2.17 | Reject null |

**Appendix Table 8. Price and Effort Elasticities for Trip Level Analysis (with lagged prices)**

| | With respect to the price of | | | | | | Effort |
|---|---|---|---|---|---|---|---|
| | Yellowfin | Albacore | Bigeye | Swordfish | Marlin | Others | elasticity |
| Swordfish trips | | | | | | | |
| Yellowfin | -0.053 | 0.082 | -0.052 | -0.239* | 0.124* | 0.139** | -0.172 |
| | (0.473) | (0.051) | (0.132) | (0.143) | (0.073) | (0.044) | (0.174) |
| Albacore | 0.327 | -0.174 | -0.278 | 0.230 | -0.190 | 0.085 | 0.190* |
| | (0.203) | (0.152) | (0.176) | (0.199) | (0.129) | (0.079) | (0.100) |
| Bigeye | -0.027 | -0.036 | 0.422 | -0.304** | -0.015 | -0.039* | 0.422** |
| | (0.069) | (0.023) | (0.591) | (0.134) | (0.040) | (0.023) | (0.208) |
| Swordfish | -0.021* | 0.005 | -0.050** | 0.071 | 0.003 | -0.009** | 2.469** |
| | (0.012) | (0.004) | (0.022) | (0.693) | (0.007) | (0.005) | (0.598) |
| Marlin | 0.247* | -0.095 | -0.058 | 0.080 | -0.152 | -0.022 | -0.059 |
| | (0.146) | (0.065) | (0.153) | (0.165) | (0.367) | (0.054) | (0.128) |
| Others | 0.374** | 0.057 | -0.198 | -0.271 | -0.030** | 0.067** | 0.036 |
| | (0.131) | (0.059) | (0.134) | (0.167) | (1.00E-4) | (0.010) | (0.054) |
| Mixed trips | | | | | | | |
| Yellowfin | 0.022 | -0.026 | -0.178* | 0.148 | -0.028 | 0.061** | 0.218 |
| | (0.783) | (0.020) | (0.093) | (0.104) | (0.042) | (0.027) | (0.307) |
| Albacore | -0.166 | 0.044 | 0.202** | -0.038 | -0.111 | 0.069 | 0.126* |
| | (0.126) | (0.213) | (0.099) | (0.106) | (0.093) | (0.070) | (0.077) |
| Bigeye | -0.079* | 0.014** | 0.078 | 0.045 | -0.027* | -0.032** | 1.064** |
| | (0.042) | (0.007) | (0.829) | (0.062) | (0.015) | (0.010) | (0.332) |
| Swordfish | 0.034 | -0.001 | 0.023 | -0.098 | 0.040** | 0.002 | 3.450** |
| | (0.024) | (0.004) | (0.032) | (0.977) | (0.009) | (0.006) | (0.639) |
| Marlin | -0.067 | -0.043 | -0.144* | 0.412** | -0.155 | -0.003 | 0.356** |
| | (0.101) | (0.036) | (0.082) | (0.092) | (0.509) | (0.039) | (0.160) |
| Others | 0.220** | 0.040 | -0.255** | 0.026 | -0.004 | -0.028 | 0.253** |
| | (0.105) | (0.043) | (0.089) | (0.097) | (0.304) | (0.066) | (0.093) |
| Tuna trips | | | | | | | |
| Yellowfin | 0.242 | 0.048 | -0.544** | 0.118 | 0.075 | 0.060 | 0.064 |
| | (1.153) | (0.096) | (0.143) | (0.076) | (0.057) | (0.058) | (0.381) |
| Albacore | 0.056 | -0.090 | -0.123 | 0.096 | 0.060 | 0.001 | 1.084* |
| | (0.122) | (1.602) | (0.170) | (0.099) | (0.069) | (0.068) | (0.589) |
| Bigeye | -0.163** | -0.032 | 0.272 | -0.073* | 0.008 | -0.013 | 1.605** |
| | (0.046) | (0.044) | (1.304) | (0.038) | (0.020) | (0.025) | (0.689) |
| Swordfish | 0.244 | 0.169 | -0.500* | -0.265 | 0.011 | 0.341** | 0.731** |
| | (0.170) | (0.174) | (0.261) | (0.906) | (0.088) | (0.101) | (0.238) |
| Marlin | 0.129 | 0.088 | 0.043 | 0.009 | -0.245 | -0.025 | 0.427 |
| | (0.105) | (0.101) | (0.116) | (0.073) | (0.928) | (0.064) | (0.352) |
| Others | 0.072 | 0.001 | -0.051 | 0.196** | -0.017 | -0.201** | 0.721* |
| | (0.078) | (0.073) | (0.106) | (0.061) | (0.973) | (0.049) | (0.366) |
| All trips | | | | | | | |
| Yellowfin | 0.048 | -0.048 | -0.130* | 0.025 | 0.047 | 0.058** | -0.020 |
| | (0.457) | (0.033) | (0.068) | (0.064) | (0.030) | (0.025) | (0.172) |
| Albacore | -0.130 | -0.014 | -0.042 | 0.112 | -0.033 | 0.107** | 0.280* |
| | (0.090) | (0.385) | (0.084) | (0.088) | (0.050) | (0.040) | (0.150) |
| Bigeye | -0.050* | -0.006 | 0.201 | -0.117* | -0.007 | -0.021** | 0.699** |
| | (0.026) | (0.012) | (0.568) | (0.046) | (0.011) | (0.010) | (0.238) |
| Swordfish | 0.006 | 0.010 | -0.072** | 0.048 | 0.013* | -0.006 | 3.429** |
| | (0.015) | (0.008) | (0.028) | (0.629) | (0.007) | (0.007) | (0.402) |
| Marlin | 0.097 | -0.026 | -0.036 | 0.113* | -0.127 | -0.021 | 0.212** |
| | (0.063) | (0.038) | (0.058) | (0.057) | (0.329) | (0.026) | (0.092) |
| Others | 0.118** | 0.081** | -0.109** | -0.047 | -0.021 | -0.023 | 0.219** |
| | (0.054) | (0.032) | (0.055) | (0.060) | (0.269) | (0.030) | (0.076) |

** = Statistically significant at the 0.05 level. * = Statistically significant at the 0.10 level.