ANALYZING THE TECHNOLOGICAL AND ECONOMIC INTERRELATIONSHIPS IN HAWAII'S LONGLINE FISHERY

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RATIONALE

- Management and regulation of marine fisheries is frequently complicated by unknown technical and economic interactions among species.
- Single species management by means of harvest restrictions without adequately understanding the nature of interactions among species may result externalities due to product transformation and substitution possibilities
- Information about species interaction is crucial to Hawaii's longline fishery, especially in the context of recent swordfish regulation

OBJECTIVES

- Analyze the nature of technical & economic interrelationships among species by specifying the multi-product dual revenue function model
- Examine the supply behavior by estimating own and cross-price supply elasticities, effort elasticities, and stock elasticities; and also examine the demand for the fishing effort.

PREVIOUS WORKS

Author Journal	Data/ Location	Fishery/species	Effort	Functional form/ Technology Tests	Price Elasticities Remarks
Diop & Kazmierczak (MRE 1996)	1989-90 Mauritania	Cephalopod fishery Octopus, Cuttlefish,Squid	HP*Trip length	Leontief Reject separability Reject nonjointness	Own: (+) inelastic Cross: (±)
Thunberg et al (MRE 1995)	1986-1989 Florida	Nearshore fishery-gill net Mullet, Seatrout, Reddrum, Sheephead, Pompano, Spot	Trip number	Translog Reject separability Reject nonjointness	Own: (+) Cross: (+)
Campbell & Nicholl (LE1994)	Papua N.Guinea	US Purse Seine vessels Albacore, Yellowfin, Skipjack	Trip length	Leontief Reject separability Reject nonjointness	Own: (+) Cross: (+)
Kirkley/ Strand (AE 1988)	1980 New Engld.	Trawl fishery Cod, Haddock, Yellowtail, Pollock, Flounder, etc	GRT*Trip length	Leontief Reject separability Reject nonjointness	Own: (±) elastic/inelastic Cross: (±)
Squires/ Kirkley (JEEM 1991)	1984 California	Pacific Coast Trawl Fishery Dover sole, Thorny heads, Sablefish, Fanfish, Flatfish	Trip length	Leontief Reject separability Reject nonjointness	Own: (±) inelastic, mostly, ns Cross: (±)
Squires (AJAE 1987)	1980-81 New Engld.	Bottom fishery Roundfish, flatfish, other	Fuel, labor, capital	Translog	Own: (+) inelastic for flatfish elastic for round fish Cross: (+)

METHODOLOGY

Dual revenue function (R): R(Z, P)

↓ Hotelling's lemma

Supply function (Q_i):
$\partial R(Z, P)/ \partial P_i$

→ System of output levels functions

↓ **Seemingly Unrelated Regression Procedure**

- Estimation of
  - Own-price elasticity
  - Cross-price elasticity
  - Output elasticity to Effort
  - Output elasticity to Stock level
  - Effort elasticity to output prices
- Non-jointness and Separability hypothesis tests

REVENUE MAXIMIZATION

- Given the fixity of capital in fishery in the short run, a fisher will be maximizing revenue by optimizing species mix and by selecting highly abundant, highly valued species along with keeping the boat engaged in fishing throughout a year.

- When there is a single composite input & marginal cost of additional input is zero, then revenue maximization is equivalent to profit maximization

LEONTIEFF REVENUE FUNCTION

$$R(Z,P) = \sum_i \sum_j b_{ij} (P_i P_j)^{1/2} Z + \sum_i b_i P_i Z^2 + \sum_i d_i P_i X_i Z$$

Where,

Z = Composite Input (NRT*Trip days)

Pi = Expected Price of i^{th} species in $/lbs

Xi = Species specific stock index

i = Swordfish, Bigeye tuna, Yellowfin, Albacore, Marlin, & Other Pelagic

OUTPUT SUPPLY FUNCTION

By Hotelling Lemma

$$Q_i(Z,P) = \frac{\partial R(Z,P)}{\partial P_i} = \sum_j b_{ij}(P_j / P_i)^{1/2} Z + b_{ii} Z + b_i Z^2 + d_i X_i Z$$

*b*s and *d*s are parameters to be estimated.

- Symmetry: $b_{ij} = b_{ji}$ *i* ¹ *j*
- Separability: $b_i = 0$ " *i*
- Nonjointness: $b_{ij} = 0$ *i* ¹ *j*

Supply Elasticities

- SUPPLY ELASTICITY:

The degree of responsiveness of quantity supplied of a particular output to changes in the price of the product

  - Price elastic: If a change in price results in a more than proportionate change in quantity supplied, supply is price elastic. I.e., $\eta_i > 1$

  - Price inelastic: If a change in price produces a less than proportionate change in the quantity supplied, supply is price inelastic. $\eta_i < 1$

- The same relationship can be established between output and effort or stock level.

Substitute and Complementary Production Relationships

COMPLEMENTARY RELATIONSHIP (η_{ij} +)

- **A**n increase in price of one species will increase production of other species

- When outputs are complements, management policy that restricts the harvest of one species also restrict the harvest of other. Then, the most easily regulated output requires regulation to reduce output levels

SUBSTITUTE RELATIONSHIP (η_{ij} -)

- An increase in price of one species will decrease the production of other species

- When two species are substitutes, effort is allocated among species on the basis of differences in relative prices. If two products are substitutes, management policy that restricts the harvest of one species will lead to increased exploitation of other.

- Single species regulation may result an unexpected product transformations. So, more than one output may require regulation.

Tests for nonjointness-in-inputs and input-output separability

- Nonjointness-in-inputs
  - independent production function
  - Single species management feasible
- Jointness-in-inputs:
  - all inputs are required to produce all outputs
  - there exists a significant interactions among species
  - Single species regulation inappropriate
- Input-Output Separability:
  - If a technology is separable between outputs and fixed inputs, the dual revenue function is separable in output prices and the composite input.
  - Species are selected based on their expected prices and prior knowledge subject to technical constraints imposed by resource availability and environmental conditions.
  - Changes in relative species prices do not have an effect on the optimal combinations of capital, labor, and fuel. Only the levels of catch and effort require regulation.

Tests for nonjointness-in-inputs and input-output separability

- Nonjointness-in-inputs implies decision about catch of one species is independent of the decision to catch other species such that each species can be separately regulated without affecting the production of other species. If the production process is jointness-in-inputs, i.e., all inputs are required to produce all outputs, then there exists a significant interactions among species.

- Input-Output Separability implies no specific interaction between any one output and any one input. If a technology is separable between outputs and fixed inputs, the dual revenue function is separable in output prices and the composite input. Species are selected based on their expected prices and prior knowledge subject to technical constraints imposed by resource availability and environmental conditions. Changes in relative species prices do not have an effect on the optimal combinations of capital, labor, and fuel. The technologies can be specified as up to a single composite output and single composite input such that only the levels of catch and effort require regulation.

SUPPLY AND EFFORT ELASTICITIES

Own price elasticity (+)

$$h_{ii} = \frac{\partial Q_i}{\partial P_i}\frac{P_i}{Q_i} = -\frac{1}{2Q_i}\left[\sum_{j \neq i} b_{ij}\sqrt{P_j / P_i}\, Z\right]$$

Cross price elasticity (±)

$$h_{ij} = \frac{\partial Q_i}{\partial P_j}\frac{P_j}{Q_i} = \frac{1}{2Q_i} b_{ij}\sqrt{P_j / P_i}\, Z$$

SUPPLY AND EFFORT ELASTICITIES

Output Elasticity of Effort

$$l_i = \frac{\partial Q_i}{\partial Z}\frac{Z}{Q_i} = \frac{Z}{Q_i}\left[\sum_{j \neq i} b_{ij}\sqrt{P_j / P_i} + b_{ii} + 2b_i Z + d_i X_i\right]$$

Effort Elasticity of Price

$$\Gamma_{Zi} = \frac{\partial Z_i}{\partial P_i}\frac{P_i}{Z_i}$$

Output Elasticity of Stock Index

$$\Phi_{is} = \frac{\partial Q_i}{\partial X_i}\frac{X_i}{Q_i}$$

Data

- Data sources
  - National Marine Fishery Services
  - Hawaii Division of Aquatic Resources
- Study period: 1991 to 1998 (before the 2000 swordfish regulation)
- Number of observations: 1271 (20% of trip records)
- Species analyzed: Bigeye tuna, Swordfish, Yellowfin, Albacore, Marlins, Others Pelagics
- Trip level information on
  - Revenues by species
  - Amount of catch sold by species
  - Prices by species
  - Composite effort (trip length*vessel net tonnage)
  - Quarterly stock indices (derived by using the no. of fish by species and number of hooks)
- Analysis by trip choices:
  - Swordfish trip
  - Tuna trip
  - Mixed trip

Variables Involved in Estimating Output Supply Functions

	Outputs (lbs/trip)			Price ($/lb)		
	Swordfish trip	**Mixed trip**	**Tuna trip**	**Swordfish trip**	**Mixed trip**	**Tuna trip**
Yellowfin	1,195	1,704	1632	2.97	3.10	2.88
Albacore	822	566	2919	0.98	1.26	1.41
Bigeye tuna	1,874	2,879	4502	3.94	3.91	3.41
Swordfish	15,781	7,123	826	3.12	2.97	2.79
Marlin	1,089	1,351	2025	1.47	1.41	1.28
Others	637	663	2234	2.37	1.83	1.50
Effort:						
Net tonnage	72.82	67.13	61.41			
Trip Length (days)	17.82	11.51	12.18			

Price, Effort, and Stock Elasticities of Supply Functions (Swordfish Trip)

Change in Output of	With respect to the Price of						Effort Elasticity	Stock Elasticity
	Yellofin	Albacre	Bigeye	Swordfish	Marlin	Other		
Yellowfin	0.0410	0.0383	-0.1386	-0.1234	0.1232***	0.0595**	-0.1467	0.3180***
Albacore	0.1677	-0.4364**	-0.1041	0.2408**	-0.0009	0.1328**	0.4860**	0.5942***
Bigeytuna	-0.0665	-0.0114	0.1791	-0.0147	-0.0524*	-0.0341*	0.3641***	0.4676***
Swordfish	-0.0089	0.0039*	-0.0022	0.0081	0.0002	-0.0012	0.2411***	0.2296***
Marlin	0.2725**	-0.0004	-0.2420*	0.0076	-0.0214	-0.0164	0.1201	0.2067
Other	0.1394**	0.0710**	-0.1665*	-0.0387	-0.0173	0.0121	0.1152	0.5518***

GENERAL ELASTICITY RESULTS

Elasticities	Sign/Significance	Remarks
Output elasticities of effort	(+) Mostly significant	Outputs responsive to effort
Output elasticities of stock	(+) Mostly significant	Supply responsive to own stock level
Effort elasticities to output prices	(+)	Higher prices would increase effort
Own-price supply elasticities	Insignificant	Outputs independent of own prices
Cross-price supply elasticities	(+,-) Mixed significance	Existence of technical-economic interactions among species

Output responsive to effort and resource levels, but independent of own prices; and efforts were quite responsive to output prices

Price, Effort, and Stock Elasticities of Supply Functions (Tuna Trip)

Change in Output of	With respect to the Price of						Effort Elasticity	Stock Elasticity
	Yellowfin	Albacore	Bigeye tuna	Swordfish	Marlin	Other		
Yellowfin	0.0476	-0.0656	-0.1631	0.0690	0.0243	0.0879**	0.2984**	0.6909***
Albacore	-0.0750	0.0528	-0.0687	0.0496	0.0233	0.0181	0.2275	0.7474***
Bigeytuna	-0.0500	-0.0184	0.1567	-0.0517**	-0.0114	-0.0253*	0.2952***	0.7955***
Swordfish	0.1404	0.0882	-0.3433**	-0.0199	0.0014	0.1332**	1.4362***	0.8459***
Marlin	0.0441	0.0370	-0.0678	0.0012	-0.0034	-0.0112	0.3184***	0.6985***
Other	0.1229**	0.0221	-0.1155**	0.0915**	-0.0086	-0.1125	0.2995***	0.2755***

Price, Effort, and Stock Elasticities of Supply Functions (Mixed Trip)

Change in Output of	With respect to the Price of						Effort Elasticity	Stock Elasticty
	Yellowfin	Albacre	BigeyeT.	Swordfish	Marlin	Other		
Yellowfin	0.0501	0.0209**	-0.0377	-0.0593	0.0254	0.0005	0.1500	0.7598***
Albacore	0.1549**	-0.0021	0.1588***	-0.2528***	-0.0753	0.0166	0.2434***	0.1749***
BigeyeT.	-0.0177	0.0101***	0.0219	0.0300	-0.0395***	-0.0048	0.3939***	0.3787***
Swordfish	-0.0148	-0.0085***	0.0160	-0.0239	0.0300***	0.0013	0.7543***	0.9336***
Marlin	0.0701	-0.0281	-0.2325***	0.3315***	-0.1405	-0.0004	0.3931***	0.1240
Other	0.0022	0.0097	-0.0448	0.0223	-0.0007	0.0113	0.3548***	0.7625***

Elasticities of Effort to Output Prices

Prices of	Effort Elasticities w.r.t. Output Prices		
	Swordfish Trip	Mixed Trip	Tuna Trip
Yellowfin	-0.067	0.122	0.146
Albacore	0.007	0.020	0.104
Bigeye tuna	0.728	0.548	0.623
Swordfish	2.225	1.813	0.295
Marlin	0.028	0.057	0.073
Other	0.029	0.052	0.057

TECHNICAL AND ECONOMIC INTERRELATIONSHIPS

Trip type	Substitute relationship	Complementary relationship
Swordfish trip	Bigeye tuna vs. Others	Swordfish & Albacore
	Bigeye tuna vs. Marlin	Yellowfin & Marlin
		Yellowfin & Others
		Albacore & Others
Mixed trip	Bigeye tuna vs. Marlin	Bigeye & Albacore
	Swordfish vs. Albacore	Swordfish & Marlin
		Yellowfin & Albacore
Tuna trip	Bigeye tuna vs. Swordfish	Swordfish & Others
	Bigeye tuna vs. Others	Yellowfin & Others

Complementary (+) and Substitute (-) Relationships Among Species in Hawaii's Longline Fishery by Trip Types

S=Swordfish trip M=Mixed trip T=Tuna trip

	Albacore			Bigeye Tuna			Swordfish			Marlins			Other Pelagics		
	S	M	T	S	M	T	S	M	T	S	M	T	S	M	T
Yellowfin	+	+	-	-	-	-	-	-	+	+	+	+	+	+	+
Albacore				-	+	-	+	-	+	-	-	+	+	+	+
Bigeye Tuna							-	+	-	-	-	-	-	-	-
Swordfish										+	+	+	-	+	+
Marlins													-	-	-

General substitute relationships: $-\eta_{LH} > -\eta_{HL}$

- The existence of substitute relationships highlights the concern that single species management of the longline fishery may have negative effects on non-regulated species stocks through unanticipated shifts in harvests.

- The lack of complementarity across all species, and especially across the important, high valued species suggests a degree of selective harvesting and incomplete joint production on the part of fishers. It may be partially attributed to the tendency of fishers to retain high priced species during initial part of the fishing trip, subsequentially filling their vessel holds with other species as the time approaches to return to port.

Tests of Nonjointness and Separability Hypotheses

	F-Value	Degree of Freedom	Pr > F	Decision $\alpha=0.05$
Nonjointness-in-inputs **($\beta_{ij}=0\ \forall\ i \neq j$)**				
Swordfish trip	2.13	15;1401	0.00	Reject Null
Mixed trip	3.85	15;3975	0.00	Reject Null
Tuna trip	1.63	15;2133	0.05	Reject Null
Input-Output Separability **($\beta_{i}=0\ \forall\ i \neq j$)**				
Swordfish trip	1.45	6;1401	0.19	Accept Null
Mixed trip	1.24	6;3975	0.28	Accept Null
Tuna trip	1.37	6;2133	0.22	Accept Null

IMPLICATIONS FOR FISHERY MGMT.

Reject *Ho* for Nonjointness → Existence of Technical-Economic Interactions

- Single species management inappropriate
- Regulations of one species may affect production of other species

Accept *Ho* for Separability →

- Biomass management possible through limited entry permit, partial area or seasonal closures

Future Undertakings

- Analysis of technological and economic interrelationships of species and vessel entry-stay-exit behavior after swordfish regulation

- Modeling longline effort dynamics and protected species interaction
  - Analyze the factors, rate, and degree of protected species interaction with longline fishing activities

  - Estimate catch-effort relationships for major species and for major fleet with a longer time series

  - Update the existing fleet dynamic model in maximizing fishery welfare and fishing effort considering broader implications on protected species.

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