Revenue Risk and Fishery Choice With Linear-Exponential Utility: An Application to Bering Sea/Aleutian Islands Trawl Fisheries

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May 1998

Selected Paper for the Annual Meeting of the
American Agricultural Economics Association
Salt Lake City, UT
August 2-5, 1998

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Abstract

This paper illustrates the use of an easy-to-use, nonlinear von Neumann-Morgenstern utility function on wealth that can represent all types of risk behavior, including neutrality. The linear-exponential (*LE*) utility specification imposes no *a priori* restrictions on risk attitude. The empirical application uses firm-level data from Alaska's groundfish fishery, indicating a diversity of individual producer risk attitudes.

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Management of modern multispecies fisheries requires an understanding of how fishermen are likely to respond to management initiatives. The effects of regulations on fishermen's choice sets and the subsequent fleetwide response with respect to species targeted, area fished, and resulting changes in catches are not well understood for most fisheries. Managers may regulate catch in one fishery and be surprised by unanticipated effects in related fisheries.

Better knowledge of what broadly can be termed “behavioral response” in fisheries is needed for at least two reasons. One reason is to help improve inseason management of catch rates among multispecies fisheries subject to binding catch quotas, to avoid premature closures when a particular quota is exhausted and others of technologically-related species are not. Also, better knowledge of fleet response to regulation is also needed for policy evaluation, i.e., for helping to decide which regulations to enact in the first place. These considerations are required for US fisheries by the Magnuson-Stevens Fishery Conservation and Management Act (PL 94-265) and by Executive Orders to promote “optimum use” and consider (to the extent practicable) both economic efficiency and the minimization of bycatch in promulgating regulations.

In characterizing fleet response to regulation, Wilen was among the first to develop models of the interaction of regulator and regulated in fisheries, and applications have been made to management of the Pacific halibut fishery (Homans and Wilen) and to the West Coast sablefish fishery (Squires and Kirkley), among others. In Alaska groundfish fisheries, some effort has been made to account for catch reallocation in response to regulation (Smith and Lloyd; Ackley), though these models do not address fishermen's choices or the technology used explicitly.

Discrete choice models of fishery participation have been implemented by Bockstael and Opaluch for the New England groundfish trawl fishery and by Evans for the California troll salmon fishery.

The purpose of this paper is to present a nonlinear discrete choice model of weekly fishery choice in the Bering Sea/Aleutian Islands (BSAI) trawl fishery. We use a von Neumann-Morgenstern utility function which is parsimonious, yet capable of reflecting a variety of risk attitudes. The "Linear-Exponential" utility function is a hybrid of negative exponential and linear utility functions, and depending on parameter values is capable of reflecting risk neutrality, risk aversion with increasing, constant, or decreasing relative risk aversion, or risk-loving behavior. Given the rich set of choices made by BSAI fishermen from among time-varying sets of target fishery alternatives, we estimate the risk attitudes of the individual producers in the fishery. We find that some 60% of producers exhibit risk neutral preferences, with nearly all the rest exhibiting decreasingly absolute risk averse preferences.

The Bering Sea/Aleutian Islands Trawl Groundfish Fisheries

There are a dozen or so distinct trawl fisheries operating on groundfish stocks in the BSAI region off Alaska. Trawl fisheries are the most significant in terms of gross product value, accounting for 87-90% of the roughly $700-850 million in first wholesale value in 1991-92. Some 70 producers used trawl gear in a fleet numbering 114 vessels in 1991 and 130 in 1992, and they were responsible for the same relative proportion of operation-weeks.

The actual catch in a given fishery may consist of dozens of species, particularly in the trawl fisheries, but the number of commercially important species groups is roughly a dozen. Table 1 gives an indication of the multispecies nature of the trawl catch and effort. Also, the trawl fisheries are the most most economically-significant of the BSAI groundfish fisheries. Substitution patterns in these fisheries are the most interesting and flexible also, given the relatively large number of species that can be targeted. Since gear changes are costly and may involve significant reconfiguring of a vessel's physical plant, trawl fisheries are the only ones where there is a significant choice to be made about what to target in the short run (e.g., within a year). For these reasons, we focus the analysis on explaining the choice of which trawl fishery to participate in from among those open each week in 1991.

The Linear-Exponential Discrete Choice Model

Several recent papers have suggested more flexible empirical formulations of the von Neumann-Morgenstern utility function used for evaluating sensitivity of producer choices to risk (Saha, 1993; Saha, Shumway, and Talpaz, 1994; Saha 1997). These specifications have more parameters (typically two rather than one) and are nonlinear in the parameters, so are capable of reflecting a wider variety of risk attitudes than the standard single parameter utility functions. The slight increase in complexity of estimation (as nonlinear optimization methods are required) is generally a small price to pay for the increased generality.

This paper suggests an alternative two parameter utility model that is equally as parsimonious, that is perhaps more appealing in terms of estimation, and, more importantly, can represent all types of risk averse behavior along with risk neutrality. The linear-exponential (*LE*) utility function is

$$u = \theta + \gamma w - \exp(-\beta w)\,, \tag{1}$$

where the two key parameters of interest are γ and β. The presence of a linear term in wealth means that risk neutrality can be represented if β=0 and γ>0. The exponential term indicates the degree of risk aversion.

Taking the first two derivatives of (1) with respect to wealth, the Arrow-Pratt measure of absolute risk aversion ($A \equiv -u''/u'$) is

(2) $$A = \frac{\beta^2 \exp(-\beta w)}{\gamma + \beta \exp(-\beta w)} \geq 0$$

and the change in *A* with wealth is

(3) $$\frac{dA}{dw} = \frac{-\gamma\beta^3 \exp(-\beta w)}{\left(\gamma + \beta \exp(-\beta w)\right)^2} = -\beta\gamma A/u' .$$

Table 2 illustrates several implications of the *LE* utility model. First, with γ>0, the model reflects risk aversion and, depending on the sign of β, can exhibit *DARA*, *CARA*, or *IARA*, since from (3) sign(*dA/dw*) = -sign(β). Second, there are two ways the model can represent *CARA*; both under risk neutrality (where it is automatically implied since *A*≡0 for all *w*) and under risk aversion. Third, when γ=0, β must be strictly positive for the model to represent economically meaningful choices. If it is not the case, the model implies nonpositive marginal utility. In empirical application, the joint hypothesis Ho: γ=0, β≤0 can be construed as a test of the model's validity, and failure to reject it is evidence that the model is inadequate to represent the behavior implied by the data set.

Similarly, the change in the coefficient of relative risk aversion (*R*≡*Aw*) as wealth changes e in this coefficient is

$$\frac{dR}{dw} = A + w\frac{dA}{dw} = A\left(1 - \beta\gamma w/u'\right).$$

Under risk aversion, *A* is strictly positive and the type of relative risk aversion as wealth changes is indicated by the sign of $\left(1 - \beta\gamma w/u'\right)$. When β>0 and γ>0, the *LE* model can exhibit *DRRA*, *CRRA*, or *IRRA*, depending on the relative magnitude of these two parameters in relation to w/u'. Table 2 shows the diversity of risk attitudes which can be represented with the LE model.

Estimation Model

A generalized choice model, as described by Judge *et al*., considers an agent *i* who faces *J* alternatives and chooses one of these. Assuming that an individual maximizes utility in wealth, the utility that the *i*th individual derives from the choice of the *j*th alternative can be represented as the "average" utility over all alternatives plus an unobserved random disturbance term. The generalized expression is

$$U_{i,j} = \overline{U}_{i,j} + e_{i,j} = \mathbf{x}_{i,j}\Gamma + e_{i,j},$$

where $\boldsymbol{x}_{i,j}$ is a (K $\times$ 1) vector of variables representing the attributes of the *j*th choice to the *i*th individual, Γ is a (K $\times$ 1) vector of unknown parameters, and $e_{i,j}$ is the random disturbance. This random disturbance reflects unobserved attributes of the alternatives. The index *K* represents characteristic variables common to all members of the population. Having specified a utility function, each individual is assumed to make a selection that maximizes their satisfaction. The probability that a particular alternative was chosen is expressed as

$$(4) \qquad P_{i,j} = \frac{\exp\left(\mathbf{x}'_{i,j}\Gamma\right)}{\sum_{j=1}^{J}\exp\left(\mathbf{x}'_{i,j}\Gamma\right)},$$

which is a general form of the logistic distribution function with the random disturbance term distributed as Weibull. It is the general form of this logistic function that is used to estimate the parameters of the *LE* utility function.

In our empirical application, the second-order Taylor series expansion of the *LE* utility model using the probability of choice expression in (4) is specified as

(5) $$P_{i,j} = \frac{\exp\left[\theta + \gamma\overline{\Omega}_{i,j} - \exp\left(-\beta\overline{\Omega}_{i,j}\right) - \beta^2 \exp\left(-\beta\overline{\Omega}_{i,j}\right)\cdot \mathrm{var}\left(\Omega_{i,j}\right)/2\right]}{\sum_{j=1}^{J}\exp[\bullet]} + e_{i,j} \ ,$$

for all 46 weeks available for participation. The *var* expression denotes variance. The parameters of this function can be expressed as vectors indexed over vessel-processors i=1...70, or jointly for the industry as a whole (assuming common utility parameters for all). Both parameter results are presented. $\overline{\Omega}_{i,j}$ represents the vector of processor's average quasi-rents for a particular week, and $e_{i,j}$ are the random disturbances associated with the unobserved attributes of the participant's choice. The denominator is the exponential sum of the utility model over all target species alternatives j=1...11. The left side of equation (5) is a vector of (0,1) probabilities of each processor participating in each of the available target fisheries, indexed over the 46 weeks. For a particular week, only a subset of the 11 fisheries are available for participation. Those available receive a probability of either one (if the processor participates) or zero (if the processor did not participate, but the alternative was available). The total observations in this sample of 46 weeks, 70 processor, and a subset of the 11 fisheries available during a particular week is 7,028.

The nonlinear program used to estimate the *LE* utility function parameters is GAMS MINOS version 5.3 (Brooke, *et al*.). The objective of the estimation program is to solve for the utility parameters by minimizing the sum of squared disturbance terms, $e_{i,j}$. The solving method uses a reduced-gradient algorithm (Wolfe, 1962) combined with a quasi-Newton algorithm (Davidon, 1959), which is implemented by following the procedures described in Murtagh and Saunders (1978). For the *LE* utility estimation, the nonnegativity constraint on the marginal utility of quasi-rents is imposed.

Standard errors on all parameters are estimated from the asymptotic covariance matrix defined as

$$\frac{\sigma^2}{n}(Q)^{-1},$$

where σ^2 is the sum of the squared disturbance terms, $e_{i,j}$, n is the number of observations, and Q is the scalar resulting from the inner product of the two gradient vectors of the objective function with respect to each of the parameters.

Results

Individual producer utility function parameter estimates are presented in Table 3, along with the implied type of risk behavior. Estimates for the whole fleet are also presented, under the hypothesis that all producers have identical utility function parameters. Results indicate that 60% of the vessel-processors exhibit risk neutrality, while 40% are risk averse. Of the risk averse producers, 64% have increasing relative risk aversion (*IRRA*), while 29% have constant relative risk aversion (*CRRA*), and 7% have decreasing relative risk aversion (*DRRA*). Assuming the same risk attitude for all operators, the industry-wide risk attitude toward quasi-rents using the *LE* utility is *DARA*. Using the mean quasi-rents across processors and target fisheries, the industry-wide relative risk aversion coefficient indicates *DRRA* for all weeks.

Because the programming equations in (11) and (12) are highly nonlinear in parameters, estimation depends critically on appropriate parameter starting values. For the *LE* utility function, this was not a problem. Results on the final parameter values were quite robust, with convergence to the reported estimates for a wide range of starting values.

Conclusions, Limitations, and Future Directions

We have estimated a nonlinear in parameters discrete choice model of the Bering Sea/Aleutian Islands trawl groundfish fisheries, using data from the 1991 fishery. This fishery is among the most economically-valuable in the world, and is complex to manage because it comprises a dozen or so commercially-important species caught in six-ten target fisheries, depending on the time of the year. The model uses a new utility function specification which is capable of reflecting a wide variety of risk attitudes. When individual risk attitudes are allowed to vary, roughly 60% were found to exhibit risk neutrality, while 40% are risk averse, with a mixture of relative risk aversion attitudes. Sixty four percent of the risk averse producers had *IRRA*, 29% had *CRRA*, and 7% had *DRRA*.

A notable feature of the model is that it relies on existing routine data collection efforts rather than costly new primary data generation. While much work needs to be done, it is hoped that these models help illustrate how one can conceptually model the important linkages between regulation and fleet response as a routine part of the management process. There are significant limitations to the existing data, particularly on costs of operation, that prevent one from taking the results of such models too seriously as yet. To get better cost estimates, some level of routine data collection on industry costs and performance is necessary. But in the meantime, it is clear that much profitable work can be done to help establish the modelling infrastructure which will also be necessary once such improved cost data do become available.

Footnotes

1. An operation-week is one operation (a catcher processor or mothership) operating for a week.
2. The exception to this rule is the pelagic (off-bottom) pollock fishery. An operation has been determined to have been targeting pollock pelagically when the composition of retained catch is at least 95% pollock. Weeks with pollock as a plurality of catch, but less than 95%, are classified as part of the bottom trawl fishery for pollock.
3. Determining the “true” target species is not always trivial in multispecies trawl fisheries. Occasionally tows come up with large unintended catches of species other than what the skipper thinks (s)he is after. Also, operations can at times covertly target some species under the guise of targetting others, so long as catch remains less in volume than the that of the target species.

Table 1. Trawl Effort and Trawl Catch Relative to Total Catch, 1991

Target Species	Effort	Catch Species	Trawl Catch	All Catch
	--Operation-weeks--		*--------metric tons--------*	
Atka Mackerel	83	Atka Mackerel	24,826	24,831
Pollock: Bottom Trawls	266	Pollock	1,032,369	1,034,675
Pollock Pelagic Trawls	647			
Pacific Cod	255	Pacific Cod	64,819	143,229
Other Flatfish	111	Other Flatfish	28,013	28,252
Rockfish	43	Rockfish	8,528	8,934
Other Groundfish	0	Other Groundfish	15,504	22,332
Rock Sole	189	Rock Sole	50,385	50,403
Sablefish	12	Sablefish	518	2,140
Greenland Turbot	0	Greenland Turbot	5,949	7,012
Arrowtooth Flounder	16	Arrowtooth Flounder	14,224	16,279
Yellowfin Sole	355	Yellowfin Sole	83,243	83,247
Discards Only	9			
Total	1,986	**All Species**	1,328,379	1,421,334

Table 2. Parameter Relationships for Absolute and Relative Risk Aversion in the *LE* utility model

	dA/dw		
dR/dw	<0 (DARA[a])	=0 (CARA)	>0 (IARA)
>0 (IRRA[b])	$\beta > 0, \gamma > 0$ $u'/w > \beta\gamma$	$\beta > 0, \gamma = 0$	$\beta < 0, \gamma > 0$
=0 (CRRA)	$\beta > 0, \gamma > 0$ $u'/w = \beta\gamma$	$\beta = 0, \gamma > 0$ RN[c]	**[d]
<0 (DRRA)	$\beta > 0, \gamma > 0$ $u'/w < \beta\gamma$	**	**

[a]DARA, CARA, and IARA refer to decreasing, constant, and increasing absolute risk aversion, respectively.
[b]DRRA, CRRA, and IRRA refer to decreasing, constant, and increasing relative risk aversion, respectively.
[c]This combination of CARA and CRRA exists only for risk neutral (RN) preferences; under risk aversion this set is empty. All other non-empty cells represent risk averse preferences.
[d]Empty set; these combinations of changes in absolute and relative risk aversion do not exist for risk averse or neutral preferences.

Table 3. Estimated Producer Risk Attitudes

	LE Utility					
	Parameter Estimates and Standard Errors				Risk Aversion Type	
Firm ID	β	st. error β	γ	st. error γ	Absolute	Relative
101	0.013	2.225	5.936	1.088	*RN*	*RN*
102	1.577	3.977	3.918	0.756	*RN*	*RN*
103	3.509	2.576	2.305	0.534	*RN*	*RN*
104	6.410	1.224	3.278	0.491	*DARA*	*DRRA*
105	4.171	2.574	3.968	0.616	*RN*	*RN*
106	1.611	2.455	6.080	1.150	*RN*	*RN*
107	0.004	1.490	6.891	1.402	*RN*	*RN*
108	1.151	2.153	4.930	0.825	*RN*	*RN*
109	4.639	2.841	1.978	0.492	*RN*	*RN*
110	6.167	6.053	2.312	0.703	*RN*	*RN*
111	6.260	0.378	2.953	0.863	*DARA*	*CRRA*
112	3.955	1.922	3.966	0.458	*DARA*	*DRRA*
113	8.379	20.441	6.059	1.093	*RN*	*RN*
114	50.346	5.248	5.263	0.964	*DARA*	*CRRA*
115	-1.757	3.774	8.972	1.295	*RN*	*RN*
116	4.371	3.860	1.902	0.438	*RN*	*RN*
117	3.795	1.998	2.171	0.598	*DARA*	*CRRA*
118	3.815	2.659	2.836	0.666	*RN*	*RN*
119	5.071	3.325	1.600	0.451	*RN*	*RN*
120	2.512	2.716	3.041	0.451	*RN*	*RN*
121	6.077	2.237	2.396	0.387	*DARA*	*CRRA*
122	1.304	1.677	4.540	1.347	*RN*	*RN*
123	5.276	2.581	1.628	0.480	*DARA*	*CRRA*
124	6.014	2.718	1.915	0.805	*DARA*	*CRRA*
125	4.588	1.983	2.219	0.962	*DARA*	*CRRA*
126	3.465	6.822	2.992	0.828	*RN*	*RN*
127	3.811	3.703	1.495	0.521	*RN*	*RN*
128	0.597	2.798	6.145	0.397	*RN*	*RN*
129	0.077	2.873	9.012	1.520	*RN*	*RN*
130	4.451	2.653	1.520	0.746	*DARA*	*CRRA*
131	2.430	3.257	4.705	0.450	*RN*	*RN*
132	1.737	2.048	4.809	0.418	*RN*	*RN*
133	5.490	3.023	1.942	1.339	*DARA*	*IRRA*
134	5.530	2.268	1.799	0.518	*DARA*	*IRRA*
135	5.768	1.814	1.983	1.171	*DARA*	*IRRA*
136	1.601	3.462	5.664	0.454	*RN*	*RN*
137	3.911	2.907	1.895	0.464	*RN*	*RN*
138	7.070	2.333	2.085	0.432	*DARA*	*IRRA*
139	0.066	3.297	8.841	0.979	*RN*	*RN*
140	3.660	1.986	1.585	0.875	*DARA*	*IRRA*
141	2.730	2.917	5.417	0.428	*RN*	*RN*
142	0.040	4.166	7.460	0.527	*RN*	*RN*
143	4.485	3.844	2.013	0.331	*RN*	*RN*
144	0.033	1.848	7.296	1.351	*RN*	*RN*
145	3.793	2.664	5.123	0.572	*RN*	*RN*

146	3.775	2.216	1.643	0.885	*DARA*	*IRRA*
147	5.483	6.087	2.367	0.351	*RN*	*RN*
148	4.037	3.824	1.490	0.456	*DARA*	*IRRA*
149	3.916	2.426	2.210	0.378	*RN*	*RN*
150	2.934	0.851	3.712	0.758	*DARA*	*IRRA*
151	1.794	0.351	4.220	0.967	*DARA*	*IRRA*
152	3.719	2.105	1.670	0.528	*DARA*	*IRRA*
153	3.801	2.098	1.490	0.727	*DARA*	*IRRA*
154	4.464	1.881	1.517	0.561	*DARA*	*IRRA*
155	14.466	0.144	1.884	0.556	*DARA*	*IRRA*
156	0.751	2.773	5.576	0.408	*RN*	*RN*
157	5.983	3.169	2.223	0.353	*DARA*	*IRRA*
158	3.914	2.458	1.443	0.604	*RN*	*RN*
159	0.209	3.932	7.526	2.212	*RN*	*RN*
160	3.740	3.381	3.689	0.393	*RN*	*RN*
161	12.465	4.608	1.687	0.697	*DARA*	*IRRA*
162	15.493	2.616	1.900	0.462	*DARA*	*IRRA*
163	3.596	2.401	1.522	0.686	*RN*	*RN*
164	5.275	2.572	1.930	0.368	*DARA*	*IRRA*
165	4.439	2.681	1.510	0.507	*DARA*	*IRRA*
166	0.158	1.677	5.717	0.363	*RN*	*RN*
167	0.514	10.010	5.066	0.715	*RN*	*RN*
168	0.824	4.468	5.206	0.347	*RN*	*RN*
169	0.046	4.358	2.141	1.754	*RN*	*RN*
170	-1.347	1.090	8.557	1.271	*RN*	*RN*
Industry-wide	4.215	0.377	2.365	0.070	*DARA*	*DRRA*

References

Ackley, D. “Bering Sea Fishery Simulation Model.” *Alaska Fish. Res. Bull.* 2(1): 83-86.

Bockstael, N. E., and J. Opaluch. “Discrete Modelling of Supply Response Under Uncertainty: The Case of the Fishery.” *J. Environ. Econ. Manage.* 10 (1984):125-137.

Evans, M. E. “An Analysis of Vessel Performance and Mobility in the California Commercial Salmon Fishery.” Unpub. PhD Dissertation, Department of Agricultural and Resource Economics, University of California, Davis, 1997.

Homans, F. R., and J. E. Wilen. “A Model of Regulated Open Access Resource Use.” *J. Environ. Econ. Manage.* 32 (January 1997): 1-21.

National Marine Fisheries Service. Magnuson-Stevens Fishery Conservation and Management Act. NOAA Technical Memorandum NMFS-F/SPO-23, Dec. 1996.

Smith, T. P., and D. S. Lloyd. “Effects of Bycatch Allocations to Trawl Fisheries for Groundfish in the Bering Sea.” Paper presented at the American Fisheries Society meeting, Anchorage, AK,1989.

Squires, D. E., and J. Kirkley. 1991. "Production Quota in Multiproduct Pacific Fisheries." *J. Environ. Econ. Manage.* 21(2): 109-126.

Terry, J. M. 1993. "Methods Used to Estimate Net Benefit per Metric Ton of Cod Catch for Each of Three BSAI Pacific Cod Fisheries for 1991 and 1992." Appendix C to the RIR/RFA for BSAI Amendment 24.

Wilen, J. E. “Towards a Theory of the Regulated Fishery.” *Mar. Res. Econom.* 1 (1985): 369-388.