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Combining Farrell Frontier and Hedonic Travel Cost Models
for Valuing Estuarine Quality

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I. Introduction

Growing public concern over deteriorations in the marine environment has created opportunities for evaluating policies based on their net benefits.

This paper proposes a methodological amendment to Brown and Mendelsohn's [1984] hedonic travel cost model, which assumes each individual acts as if he faces a different "price" function for the services of heterogeneous recreation sites. By observing how recreationists make decisions when facing different marginal costs for site attributes, the demand for each attribute can be estimated.

Unfortunately, experience with Brown-Mendelsohn's model has revealed problems.¹ In the absence of a market equilibrium, the theoretical basis for their price functions is unclear. Prior applications of the model estimated price functions for residential zones, combining the opportunities of individuals living close to each other and assuming that each faced the same implicit prices. Finally, ordinary least squares (OLS) estimates of the price functions frequently implied negative marginal prices for desirable characteristics.

Our modification to the Brown-Mendelsohn framework estimates a "price" function for each person as a best-practice Farrell [1957] frontier. It also addresses the other limitations identified for the hedonic travel cost model and finds robust benefit estimates for improving the characteristics of an estuary. The application used to illustrate our method has independent interest because it estimates the value of improving the quality of sport-fishing in the Albemarle-Pamlico Estuary in North Carolina, one of the first estuaries to enter the National Estuarine Program.

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II. The Hedonic Travel Cost Model

A hedonic price function is an equilibrium relationship describing how the prices for a set of closely related but heterogenous commodities must be related to the commodities' characteristics to ensure that no incentives exist for buyers or sellers to renegotiate the sales. The hedonic travel cost function hypothesized to describe how individuals perceive their recreation choices does not arise in this way. Instead it is a maintained assumption describing how each person conceives of the available recreation sites based on the incremental travel cost required for more of each site characteristic. Each individual has different implicit costs for sport-fishing based on the accessibility of marine recreation sites and the availability of leisure time. They imply a different hedonic cost function for each recreationist. Because of these functions, the Brown-Mendelsohn model can use the Rosen [1974] two-step method to estimate demands for site characteristics.²

Our implementation of the model introduces three changes: (1) Hedonic travel cost functions are estimated at the lowest level of geographic aggregation supported by the data, and marginal prices are allowed to vary for each person.³ (2) The time horizon for recreation decisions is assumed to be a single trip, not a season as in past applications. This specification parallels the formulation used for random utility models and avoids concerns raised by Smith and Kaoru [1987] on measuring site characteristics. And (3), the estimation of the first-step "price" (i.e., travel cost) functions is treated as a problem of isolating the "best-practice" locus of opportunities where more costly sites are relevant only when they offer increases in some attributes.

This last change is perhaps the most important. The conventional approach for estimating these price functions treats each as a type of "average"

reflecting the travel cost/site characteristics' gradients inherent in the set of alternatives defining each recreationist's choice set. Two aspects of our use of a Farrell [1957] frontier require further discussion. Farrell's method implicitly maintains that there is a distribution of practices across the micro units used to compose a frontier (whether production or cost), and by selecting the locus of highest (lowest) points for the observed output/input (cost/output) combinations, the method defines an efficiency standard based on the observed best practice (see Kopp [1981]). It does not provide a behavioral description of why the individual micro units depart from that efficiency standard. As Forsund, Lovell, and Schmidt [1980] observed, this strategy seems to be "at odds" with an optimizing view of the economic agents' behavior.

This criticism is not relevant to our proposed use of the frontier because the observations defined as alternative recreation sites describe the analyst's judgment on what each recreationist knows is available. By specifying a frontier model to describe recreationists' perceptions of the marginal costs of acquiring additional amounts of desirable site attributes, we assume recreationists seek to acquire them in the most efficient way possible--a hypothesis consistent with the conventional optimizing view of individual behavior. Equally important, this approach reduces the sensitivity of marginal costs estimates to the definition of the choice set because only the "best" (least-cost sites) determine the position of the locus. An additional advantage of this approach is that marginal costs of desirable site attributes are constrained to be non-negative.

Of course, our approach does not address the issue of defining the set of alternative sites hypothesized to be considered by each individual. The definition of the choice set should be acknowledged as the analyst's modeling judgment. With most available data sets, we will not know all the alternatives an individual considered. Our strategy limited them to sampled entry points to

the Albemarle-Pamlico Sounds. We could have expanded this set to include alternatives elsewhere along the Atlantic Coast or, indeed, at any coastal locations providing access to sport fishing. While these judgments affect our results, they are not unique to a frontier specification for the hedonic travel cost model. Brown and Mendelsohn's proposed solution for this question used sites visited by recreationists in their residential zones to define their choice set. Moreover, the same issue arises in random utility (see Manski [1977]) and conventional demand models (see Smith [1990]).

Following Brown and Mendelsohn, we assume these travel cost functions are linear in site characteristics. The frontiers can be estimated by solving linear programming (LP) problems defined for each recreationist in our sample. Equations (1) and (2) define the LP problem with the estimated marginal prices given by the $\hat{\alpha}_j$'s.

$$\text{Minimize}_{\hat{\alpha}} \quad \sum_{i=1}^N \hat{\epsilon}_i \quad (1)$$

$$\text{subject to: } t_i - \hat{\alpha}_0 - \sum_{j=1}^K \hat{\alpha}_j C_{ji} > 0, \quad i=1, 2, \dots, N \quad (2)$$

$$\hat{\alpha}_j \geq 0, \quad j = 0, 1, \dots, K$$

$$\text{with } \hat{\epsilon}_i = t_i - \hat{\alpha}_0 - \sum_{j=1}^K \hat{\alpha}_j C_{ji}$$

where i indexes sites (N), j indexes attributes (K), t_i is travel cost, and C_{ji} are site attributes.

The set of $\hat{\alpha}_j$'s that minimize (1) will be independent of the value for $\sum_{i=1}^N t_i$, so this term can be dropped from the objective function in (1), and the remainder is a standard linear programming problem.

Because our sample only identifies a recreationist's county of origin, we cannot distinguish the opportunities for individuals at different locations within a county. Instead we measure the round-trip distance from a central point

in each origin county to all the boat and bank fishing sites identified in our sample. Frontier functions can be estimated using round-trip distance in place of t_1 and the coefficients rescaled to reflect the travel and time costs of each mile (see below for details).

III. Data, Model Implementation, and Results

Our analysis is based on an intercept survey with 1,012 interviews conducted during the 1981 and 1982 recreational fishing seasons (see Johnson et al. [1986]). Boat fishing parties account for 71% of the sample. Seventy percent of the interviews were conducted on weekends. The survey includes detailed information about each party's fishing trip: when it occurred, the fishing equipment used, fish caught, and recreationists' socioeconomic characteristics (including household income). Data were available for 35 boat sites and 44 bank sites. Travel costs were estimated to include the vehicle operating costs (round-trip mileage times \$.20 based on Insurance Information Institute estimates) and the opportunity cost of travel time. The opportunity cost of travel time was assumed to be a predicted wage for those who were working. (See Smith and Palmquist [1989] for complete details).

These specifications for the components of travel and time costs are judgments that will affect the level of any benefit estimates for quality improvements derived from our model. However, they are unlikely to affect the relative performance of OLS versus frontier models because the same scaling factor is applied to compute the marginal cost for each recreationist with each method. Because our results are intended to be illustrative, we have not reported a detailed analysis of the effects of these decisions.

The site characteristics include an estimate of fish availability (average number of fish caught per person/per hour for each entry point) and measures of

the effluent loadings (nitrogen and phosphorus) from each coastal county as proxies for water quality in each location. The catch rate was measured separately for boat and bank fishermen. The effluent loadings are estimates from NOAA's National Coastal Pollutant Discharge Inventory of point, nonpoint, and upstream sources of effluents for the base period 1980-85.

Estimates for hedonic travel cost functions were developed for 117 functions for the origins of the boat fishing parties and 87 functions for the origins of bank fishing parties using both the Farrell LP frontiers and the OLS estimates in each case. Because these travel cost functions provide estimates of the marginal costs for each of the three site characteristics (i.e., the catch rate and the nitrogen and phosphorus loadings defined in inverse form to imply positive amenities), second-stage demand models were developed for each. In this paper, we focus on the catch rate measure of site quality both because it is the most common measure used to characterize the quality of sport fishing and to economize on space. A complete discussion of the findings is available in Smith, Palmquist, and Jakus [1989].

Four aspects of our results will be summarized: (1) a comparison of the key feature of OLS estimates of characteristics' prices--negative values--in relationship to the corresponding frontier estimates for the same recreationists; (2) the estimated "technical efficiency" of recreationists' site selections; (3) the second-stage, inverse demand models using both frontier and OLS prices for the catch rate; and (4) benefit estimates for quality improvements.

Figure 1 compares the marginal prices estimated with frontier functions with those estimated with OLS. It considers only those recreationists assigned a zero price for catch using the frontier cost functions and plots the cumulative frequency distribution for the corresponding OLS price estimates these same individuals were assigned. OLS estimates implying negative values accounted for almost 80 percent of the bank fishing estimates but fell within a narrow range (about -1.5 to 0), while negative estimates for boat parties accounted for a

somewhat smaller fraction of their sample (about 70 percent) but have a larger range.

On the whole, the site selection decisions of boat fishing parties would be judged as quite efficient, with 74.6 percent having a cost-based efficiency index comparable to a Farrell output measure (bounded between 0 and 1) exceeding .75. The bank fishing parties exhibited a somewhat less efficient record with 66.2 percent greater than .75. These efficiency indexes did not appear to be related to the demographic characteristics, fishing mode, or experience of recreationists.

Second-step demand models for catch were estimated both with marginal price and with quantity as dependent variables. Partial inverse demands (i.e., with marginal price as the dependent variable) are often used because they provide a convenient way to recognize the stochastic nature of estimated characteristics' prices. Table 1 summarizes our results for each party type using both the OLS and the frontier marginal prices. The most complete specification includes the relevant level of the catch measure, household income, the marginal prices for the other two site characteristics, the respondent's age, experience at fishing (measured as years fishing), and, for boat fishing parties, the horsepower of the boat used. For the models based on the OLS price estimates, models using the full sample and a subsample confined to those with positive marginal price estimates are reported. This restriction has a substantial influence on the perceived plausibility of the model for both types of fishing parties. Without it, the relationships are negative and significant. With it, the models yield insignificant associations between the marginal prices and catch, but the benefit estimates implied are negative and therefore implausible.

Models using the frontier estimates are more encouraging. The catch rate/marginal price associations are negative and significant. Tobit was also used in case the estimates were sensitive to the treatment of the zero estimates for marginal prices. Our findings for the conventional demand models confirm

the results with the inverse specification--a significant negative association between the marginal price and catch.⁴ The results for the other two site characteristics (our inverse measures for phosphorus and nitrogen) also imply a negative and significant relationship, but not for both types of fishing parties. (See Smith, Palmquist, and Jakus [1989] for details.)

IV. Valuing Quality Changes

One important motivation for understanding how the quality of sport fishing opportunities affects people's decisions is the requirement that major estuaries develop conservation and management plans considering the benefits and costs of policy alternatives. To illustrate this use and provide another basis for comparing our extension to the hedonic travel cost model, we calculated the estimated benefits (in 1982 dollars) per person per trip for improvements in the catch rate. Table 2 reports these results using the frontier estimates of marginal prices with Tobit estimates for the simplest and most detailed specifications of the inverse demand functions and the estimates of conventional demand models. Because predictions from these partial inverse demand models should be positive, we used the inverse Mills ratio to adjust the Tobit estimates so that the consumer surplus corresponds to the area under the function defined by the conditional expectation $E(\hat{\alpha}|\alpha^* > 0)$ where $\hat{\alpha}$ is the estimated marginal price and α^* the true marginal price for catch. Unlike the results reported in Bockstael, Hanemann and Kling [1987], these estimates fall within the range of values reported from RUM models for valuing catch rate improvements in sport fishing trips (see Bockstael, McConnell and Strand [1990]).

ENDNOTES

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1. See Bockstael, Hanemann and Kling [1987]; Bockstael, McConnell and Strand [1989]; and Smith and Kaoru [1987] for discussion of the problems identified.
2. This application in its simplest form assumes the first-step cost functions are linear so the marginal prices are constant.
3. Brown and Mendelsohn [1984] also estimated their first-step equations in terms of distance and travel time and then scaled the parameters to estimate marginal prices. They assumed these equations would be constant for all individuals in a residential zone, but allowed for a similar type scaling of the coefficients based on each individual's income per hour.
4. The specific estimates using OLS are:

[Boat Fishing]

$$\begin{array}{llll} \text{Catch} = 4.62 & - .66 & \text{Price Catch} = .14 \times 10^{-4} \text{ Income} & - .02 \text{ Age} \\ (8.21) & (-3.14) & (-1.93) & (-1.54) \end{array}$$

$$+.02 \text{ Years Fishing} = .85 \times 10^{-3} \text{ Price Nitrog Inv} \quad (3)$$

$$(1.32) \quad (-1.50)$$

$$+.16 \times 10^{-2} \text{ Price Phos Inv} = .31 \text{ Horse Power} \quad R^2 = .06$$

$$(-0.39) \quad (-0.39)$$

[Bank Fishing]

$$\begin{array}{llll} \text{Catch} = 20.45 & - 11.35 \text{ Price Catch} = .73 \times 10^{-4} \text{ Income} \\ (3.24) & (-4.55) & (-1.13) & \end{array}$$

$$-.12 \text{ Age} + .05 \text{ Years Fishing} = .17 \times 10^{-2} \text{ Price Nitrog Inv} \quad (4)$$

$$(-1.48) \quad (0.55) \quad (-0.32)$$

$$-.02 \text{ Price Phos Inv} = .23 \times 10^{-3} \text{ Horse Power} \quad R^2 = .17$$

$$(-2.60) \quad (-0.05)$$

t-ratios are in parentheses below the estimated coefficients.

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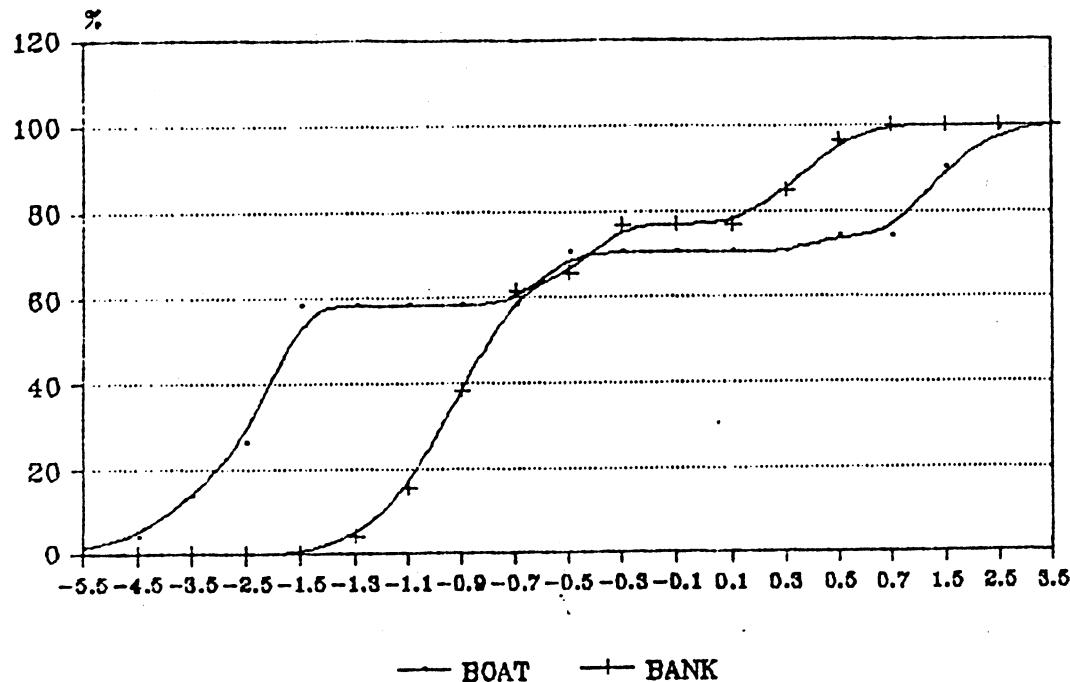
TABLE 1: Second Step Inverse Demand Models for Catch Rate^a

	BOAT FISHING						BANK FISHING					
	OLS Marginal Prices ^b			Frontier Marginal Prices			OLS Marginal Prices ^b			Frontier Marginal Prices		
	ALL	ALL	POSITIVE	OLS	TOBIT	TOBIT	ALL	ALL	POSITIVE	OLS	TOBIT	TOBIT
Intercept	-1.242 (-5.394)	-0.326 (-1.672)	-1.244 (-4.505)	0.623 (4.791)	-0.111 -0.689	0.195 0.658	0.219 (5.048)	0.041 (0.682)	0.195 (6.652)	0.787 (6.578)	0.491 (6.198)	0.831 (6.052)
Catch Rate	-0.057 (-3.379)	-0.072 (-2.638)	-0.008 (-0.449)	-0.030 (-3.229)	-0.076 (-3.801)	-0.100 (-4.017)	-0.62x10 ⁻² (-6.136)	-0.017 (-7.109)	0.25x10 ⁻² (0.52)	-0.011 (-4.587)	-0.023 (-4.946)	-0.020 (-5.213)
Income	-.91x10 ⁻⁵ (-3.276)	.31x10 ⁻⁵ (0.694)	-0.50x10 ⁻⁵ (-2.125)	.21x10 ⁻⁵ (1.344)	.32x10 ⁻⁵ (0.888)	.31x10 ⁻⁵ (0.854)	.32x10 ⁻⁶ (0.414)	-.67x10 ⁻⁶ (-0.340)	.11x10 ⁻⁵ (2.379)	.35x10 ⁻⁵ (1.765)	.31x10 ⁻¹ (1.200)	.30x10 ⁻⁵ (1.329)
Marginal Price Inverse of Nitrogen	-0.13x10 ⁻³ (-0.329)		0.35x10 ⁻² (6.072)	-0.31x10 ⁻³ (-2.630)		-0.001 (-3.437)	-0.14x10 ⁻³ (-1.233)		0.10x10 ⁻³ (1.292)	0.11x10 ⁻³ (0.654)		.65x10 ⁻⁴ (0.331)
Marginal Price Inverse of Phosph.	0.004 (27.89)		0.32x10 ⁻³ (11.245)	0.18x10 ⁻³ (1.49)		0.80x10 ⁻³ (2.756)	-0.87x10 ⁻³ (-15.479)		-0.77x10 ⁻³ (-28.553)	-0.13x10 ⁻² (-6.921)		-0.13x10 ⁻² (-5.922)
Age	-0.72x10 ⁻³ (-0.150)		0.001 (0.239)	-0.44x10 ⁻² (-1.656)		-0.012 (-1.812)	-0.70x10 ⁻³ (0.75)		-0.72x10 ⁻³ (-1.129)	-0.13x10 ⁻² (-0.548)		-0.14x10 ⁻² (-0.530)
Years Fishing	0.36x10 ⁻² (0.816)		0.47x10 ⁻² (1.197)	0.22x10 ⁻² (0.893)		0.009 (1.466)	-0.16x10 ⁻² (-1.561)		0.001 (1.449)	-0.002 (-0.745)		-0.26x10 ⁻² (-0.879)
Horsepower of Boat	0.05x10 ⁻² (0.637)		.39x10 ⁻³ (0.483)	-0.68x10 ⁻³ (-1.457)		-0.15x10 ⁻³ (-0.382)						
n	493	493	249	493	493	493	154	164	72	154	154	154
R ²	0.67		0.383	0.057			0.898	0.243	0.946	0.404		

^aThe numbers in parentheses below the estimated coefficients are the ratios of these estimated coefficients to their standard errors. With OLS under the assumption of normality, these are t-ratios. With Tobit they are asymptotically normal statistics. In both cases, we use them as a gauge of the ability to reject the null hypothesis of no association with the estimated marginal price.

^bThe column headings define the sample composition. ALL designates the full sample. POSITIVE designates the sample where marginal price estimates are restricted to be positive.

FIGURE 1: Catch Rate

TABLE 2: Benefit Measures for Frontier/HTC Models
to Value Catch Changes^a

Models	Boat Sample	Bank Sample
Simple Inverse Demand	\$1.02 (1.00)	\$.62 (.60)
Detailed Inverse Demand Model	\$.82 (.72)	\$.79 (.77)
Conventional Demand	\$2.86 (1.35)	\$1.11 (1.02)

^aThese estimates are consumer surplus per trip in 1982 dollars based on the equations in columns 5 (simple), and 6 (detailed) for the Boat sample and columns 11 and 12 for the Bank sample. The conventional demand models are reported in footnote 4. All other variables in these models were held at the relevant sample means. The inverse Mills ratio was treated as a constant and evaluated at the sample mean in the estimation of the consumer surplus.

The first estimate in each row is for an increase of one fish per hour per person in catch rate from 1.64 to 2.64 and the value below it in parentheses for increases for 2.64 to 3.64.