MODELING NONLINEAR PREFERENCES

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Abstract: Economic theory, as well as intuition, supports the notion of increasing or decreasing marginal rates of substitution. That is, the marginal benefit derived from an increase in a desired good or service, or one's willingness to accept tradeoffs among various costs or benefits, depends on the current mix or allocation. However, due to widespread availability and ease of use, linear models are frequently used to model preference structure for environmental goods or services. This paper presents an approach for estimating nonlinear effects and contrasts the results with those of linear models. The effects on the optimal choice in multiattribute decisions and acceptability of tradeoffs among costs and benefits are highlighted.

Introduction

Economic theory, as well as intuition, supports the notion that preferences for most types of goods or benefits are nonlinear. The value placed on obtaining an additional unit of a good or achieving the next level of an objective usually depends on the current level. That is, the marginal benefit derived from an increase in a desired good or service, or one's willingness to accept tradeoffs among various costs or benefits, depends on the current mix or allocation. However, due to widespread availability and ease of use, linear models are frequently used to model preference structure for environmental goods or services. This paper presents an approach for estimating nonlinear effects by examining the relative values that private landowners place on various attributes of forest management.

Privately owned forests comprise nearly three-quarters of the forest land in the United States and are expected to play an important role in meeting future needs for timber, recreation, wildlife habitats, and many other forest-related benefits (USDA Forest Service, 1988; 1995). There is concern that these lands may not meet their potential in achieving objectives related to overall ecosystem health and sustainability, nor in providing benefits that transcend legal and political boundaries, e.g., biodiversity, water quality, and habitat for certain kinds of wildlife.

Surveys of private forest-land owners conducted by the USDA Forest Service show that many owners hold their woodland primarily for noncommercial reasons (Birch, 1996). Many people own forest land because it is part of the farm or residence, for aesthetic enjoyment, to view wildlife, or participate in other forms of forest-related recreation. Landowner attitudes and motivations suggest that they are favorably disposed to providing nontimber benefits and protecting the health of the forest ecosystem. However, the large number of owners, diversity of objectives, increasing fragmentation, and nonmarket nature of many benefits pose problems in estimating what can be expected from these lands and in designing policy to influence behavior (Dennis et al., 2000). We need to better understand the relative importance that landowners attach to various objectives as well as their willingness to incur costs associated with achieving these benefits. This information is relevant for policy formation and as an input to larger analytical models.

Conjoint techniques were used to solicit landowner preferences for management involving varying levels of timber harvesting, recreational trail improvement, apple tree maintenance to benefit wildlife, protection of a rare species of fern, and cost. The nonlinear nature of the relationships among the variables is explicitly explored. An ordered probit model is used to estimate preferences. The results are used to compute marginal rates of substitution (MRS), that is, the tradeoffs that landowners are willing to make to achieve changes in the levels of other objectives.

Methods

The Dillman (1978) Total Design Method was used to design a survey that was mailed to 1,250 forest-land owners who hold at least 10 acres of forest land in Franklin County, Massachusetts. In addition to answering questions on his or her attitudes toward land management and demographics, each respondent completed a conjoint survey. The useable response rate was 61.3 percent.

Conjoint analysis is a technique for measuring psychological judgments and is frequently used in marketing research to measure consumer preferences (Green et al., 1988). Respondents make choices between alternative products or scenarios that display varying levels of selected attributes. The utility of each attribute can be inferred from the respondent's overall evaluations. These partial utilities indicate the relative importance of each attribute's contribution to overall preference or utility. They can be combined to estimate relative preferences for any combination of attribute levels. Conjoint techniques are well suited for soliciting and analyzing preferences in environmental decisions that frequently entail tradeoffs between costs and benefits that are not represented efficiently in market transactions.

Forest-land owners in Franklin County were asked to rate four alternative management scenarios for a hypothetical forested property shown in a figure within the survey. The figure included an area of apple trees, a section of rare ferns, and a recreational trail that passed through the sample property. Each alternative was rated on a scale of 1 to 10, with 10 representing alternatives that they definitely would undertake and 1 those that they definitely would not undertake. Ratings of 2 to 9 represent how likely they would be to undertake alternatives about which they were unsure. Each alternative varied by one or more of the following five attributes: the proportion of the apple trees to maintain on the hypothetical property, the proportion of rare ferns to protect, the extent of the trail network to improve, the extent of timber harvesting, and cost. An orthogonal array was used to create a succinct subset of attribute combinations that allows estimation over the entire range of attribute values (3^5 = 243 possible combinations). The resulting 18 alternatives were assigned

to questionnaires in equal frequency. Each alternative consisted of a unique bundle that included all five individual attributes. Each attribute had one of the three possible levels appearing in parentheses. Alternatives appeared as follows:

- Maintain (none/half/all) of the apple trees shown on the figure that benefit wildlife.
- Protect (none/half/all) of the acres containing a rare species of fern shown on the figure by not harvesting timber in this area or otherwise disturbing the ferns.
- Improve (none/half/all) of the trail network shown on the figure. Improvements, if any, would include the cost of building a footbridge over the stream and clearing scenic vistas.
- Harvest timber from (none/half/all) of the lands shown on the figure. Any harvest would be selective, designed to remove poorly formed and leave some high-quality trees; 25 to 30 percent of all trees would be removed.
- This option would have a net cost to you of $ (50/250/500).

A secondary objective of the survey was to examine landowner attitudes about collaborative management. Landowners were partitioned into two groups. Each group received an identical questionnaire except one group that was asked to imagine that they owned a portion of the hypothetical property described earlier and to rate their willingness to cooperate with adjoining landowners to achieve the management objectives depicted by the alternatives. Because the objective here is to illustrate the conjoint technique and a procedure for estimating nonlinear effects on preferences and not collaboration, responses for both groups are pooled for estimation.

A random utility model was used to explain forest-land owner preferences. When presented with a set of alternatives, individuals are assumed to make choices that maximize their utility or satisfaction. The utility that the ith individual derives from the jth alternative (U_{ij}) can be represented as:

$$U_{ij} = X'_{ij}\beta + e_{ij}$$

where X_{ij} is a vector of variables, which may include transformations of variables, that represent values for each of the five attributes of the jth alternative to the ith individual; β is a vector of unknown parameters; and e_{ij} is a random disturbance, which may reflect unobserved attributes of the alternatives, random choice behavior, or measurement error. In the empirical study under consideration, a respondent's utility level (U_{ij}) for each alternative is not observed, but a rating (r_j) is observed that is assumed to proxy for his or her underlying utility.

Following McKenzie (1990, 1993) and others, the analytical capabilities of the conjoint rating model can be illustrated by assuming that rating (r_j) can be modeled as a linear combination of the variables representing the attribute levels. Typically, only linear effects are considered but we modify the analyses to include quadratic effects to test for nonlinear relationships:

$$r_j = a + b_1x_{1j} + b_2x_{2j} + ... + b_nx_{nj} + q_1x_{1j}^2 + q_2x_{2j}^2 + ... + q_nx_{nj}^2$$

The estimated partial utilities are the combined linear (b_n's) and quadratic (q_n's) effects of a discreet change in the level of the associated attribute on overall preference. Relative overall preference for any alternative (combination of attribute levels) can be determined by summing across Equation 2.

The MRS is the rate at which an individual is willing to trade one good for another while remaining equally well off (Nicholson, 1978). The MRS or acceptable tradeoff of one attribute for another is determined by the ratio of the marginal responses. Setting the total differential of (2) to the point of indifference and solving yields the marginal rates of substitution or the acceptable tradeoffs for the respective attributes:

$$dr_j = b_1dx_{1j} + b_2dx_{2j} + ... + b_ndx_{nj} + 2q_1x_1dx_{1j} + 2q_2x_2dx_{2j} + ... + 2q_nx_ndx_{nj} = 0$$

$$dx_{1j} / dx_{2j} = -(b_2 + 2q_2x_2) / (b_1 + 2q_1x_1)$$

Results

Seventy-eight percent of Franklin County is forested, most of which is in nonindustrial private ownership. The average respondent owned 60 acres of forest land, and 70 percent of the parcels were fewer than 100 acres. Nearly 80 percent of the respondents lived within 5 miles of their woodland, 60 percent had owned their land more than 15 years, and one-third had a management plan. Approximately half of the owners were 55 or older, and 74 percent had completed at least 1 year of college.

The model was estimated using a polychotomous probit technique developed by McKelvey and Zavoina (1975) to analyze ordinal level dependent variables. The dependent variable (r_j) is the rating for each alternative scenario and was coded from 0 to 9. The explanatory variables (attributes) were coded 0.0, 0.5, and 1.0 to account for the proportions of apple trees to maintain, trail improvements, fern protection, and extent of timber harvesting. Cost was coded in units of $100 (0.5, 2.5, and 5.0). Each respondent rated four alternatives for a total of 2,504 rated scenarios. The results are shown in Table 1.

The estimated signs and relative magnitudes of the coefficients provide information on the respondents' preferences. As expected, increased levels for each of the attributes except cost had a positive effect on ratings. The magnitude of the positive effects of maintaining apple trees to benefit wildlife and fern protection were greater than those for trail improvements and extending the area available for timber harvesting (which also can be interpreted as lower restrictions on harvesting). Landowners, therefore, generally placed higher value on wildlife and other nontimber amenities (Birch, 1996; Brunson et al., 1996) and with the attitudinal aspects of this survey (Rickenbach et al., 1998).

Table 1. Ordered Probit Parameters for a Multiattribute Conjoint Rating Survey (Dependent Variable = Rating, Coded 0 to 9, N=2,504)

Variable	Coefficient	Std. error	t-ratio
Constant	-0.1785	0.0701	-2.55
Linear effects:			
Apples	1.1019	0.1955	5.64
Ferns	1.3040	0.1871	6.97
Timber	0.2142	0.0521	4.11
Trails	0.8580	0.1863	4.61
Cost	-0.0415	0.0116	-3.57
Quadratic Effects:			
$(Apples)^2$	-0.5264	0.1836	-2.87
$(Ferns)^2$	-0.6996	0.1784	-3.92
$(Trails)^2$	-0.6570	0.1841	-3.57

All variables were significant at the 1% level.
Log-likelihood = 5179.1

A commonly accepted economic precept with intuitive appeal is that one's preference for more of a particular good depends on how much of the good one already has and that willingness to trade among goods depends on the quantities of each good in one's possession. Quadratic effects were examined to estimate these expected nonlinear relationships. The quadratic terms for apple tree maintenance, fern protection, and trail maintenance were negative and statistically significant, which indicates decreasing marginal benefits for these attributes. The partial utility or the contribution of an individual attribute toward the total utility provided by an alternative is determined by combining both the linear and quadratic effects at a given attribute level. For example, the partial utilities for fern protection at levels none, half, and all are 0.0, 0.477, and 0.604, respectively (computed as $b_i x_i + q_i x_i^2$). Thus the increase in utility resulting from an increase in fern protection from none to half is 0.477, while the increase from half to all is 0.127. It appears that marginal increases in utility decreased once respondents believed that a significant portion of the ferns were protected or the apple trees maintained. Although respondents favored initial trail improvements, similar calculations indicate that maintaining all of the trail network versus just half actually decreased overall utility or preference for an alternative.

To examine the tradeoffs that respondents were willing to accept among the objectives marginal rates of substitution can be computed for any two attributes at the selected levels using Equation 3. The tradeoff between cost and attaining management objects is frequently useful to policymakers. The MRS between cost and the other attributes shown in Table 2 illustrate the notion of decreasing marginal benefits. Landowners were willing to incur less additional cost to maintain apple trees or protect ferns as the amounts of these attributes already under protection increased. For example, landowners on average were willing to incur a cost of $23 to protect an additional percentage of the ferns if only 25 percent were currently under protection, but only $6 if 75 percent already were being protected.

The trade-offs that landowners are willing to accept between two attributes may be determined at any level selected for each attribute by computing the MRS for the attributes directly using Equation 3 or by comparing the MRS between each attribute and cost. For example, if half of the apple trees are currently being maintained, Equation 3 can be used to determine the level at which landowners become indifferent between additional trail improvements and increased apple tree maintenance. The MRS equates to one when apple tree maintenance is at 50 percent and trail improvement is at approximately 21 percent. Thus landowners would prefer to improve the trail network up to the 21-percent level over additional apple tree maintenance at 50 percent. At this level, landowners would be willing to incur the same additional cost to improve an additional 1 percent of the trail network or to maintain an additional 1 percent of the apple trees.

Table 2. Marginal Rates of Substitution, Cost ($) per 1-percent Increase in Listed Variable at Indicated Initial Level

Level	Apples	Ferns	Trails	Timber
0.00	26.54	31.40	20.66	5.16
0.25	20.20	22.98	12.51	5.16
0.50	13.86	14.56	4.36	5.16
0.75	7.52	6.13	*	5.16
1.00	1.18	*	*	5.16

* Negative

Summary

Nonindustrial, privately owned forests are expected to play an important role in meeting needs for a wide range of forest-related benefits. Estimates of the relative values that landowners place on various nonmarket benefits provided by their land and the costs they are willing to incur to achieve different levels of these benefits are useful to policymakers. Conjoint techniques are well suited for assessing the relative values and acceptable tradeoffs (MRS) among various management objectives. Including quadratic effects allows estimation of nonlinear MRS, which economic theory and these empirical results suggest are important.

Landowners in Franklin County, Massachusetts, generally placed higher values on the ecological aspects (fern protection and apple tree maintenance) of management alternatives than on use-related aspects (timber harvesting and recreational trail improvements). Both fern protection and apple tree maintenance exhibited decreasing marginal rates of substitution. Although landowners feel strongly about providing these benefits, their willingness to make tradeoffs between these and other objectives or to incur additional cost depended greatly on the current levels to which the objectives were being met.

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