# Analyzing Public Inputs to Multiple Objective Decisions on National Forests Using Conjoint Analysis

Donald F. Dennis

**ABSTRACT:** Faced with multiple objectives, national forest managers and planners need a means to solicit and analyze public preferences and values. A conjoint ranking survey was designed to solicit public preferences for various levels of timber harvesting, wildlife habitats, hiking trails, snowmobile use, and off-road-vehicle (ORV) access on the Green Mountain National Forest. The survey was completed by 76 respondents during public involvement meetings. An ordered probit model was used to estimate linear and quadratic main effects. Respondents preferred moderate levels of timber harvesting and snowmobile access and lower levels of ORV access. They favored a mixture of mature closed canopy and younger more open forests over either extreme and were somewhat indifferent toward extending the network of hiking trails. For. Sci. 44(3):421–428.
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An ever increasing population is demanding more of everything, including preservation, from forests and other natural environments. Resource managers must make decisions that balance the diverse needs, wants, values, and beliefs of society while ensuring the long-run integrity and sustainability of extremely complex ecological systems. Managers and policymakers consider values that range from forest health, biodiversity, and global climatic change to production and sustainability of wood products, wildlife habitats, and opportunities for outdoor recreation. Because desires differ widely across society, conflict and expensive litigation frequently arise over the choice of management strategy and resulting mix of benefits. Conflicts are particularly acute on public lands where managers often feel trapped in a lose-lose situation by the competing demands of vocal and unyielding groups of stakeholders.

Biophysical information and technical expertise alone are not sufficient for choosing among alternate management strategies. Salwasser (1994) stressed the importance of human choice in ecosystem management: "...the success or failure of ecosystem management in protecting environments, revitalizing economies, or restoring healthy communities starts and ends with people and their choices—not with nature preserves, databases, ecological classifications, or any other technological tools that are merely useful means to desired ends."

Others, including Cortner and Shannon (1993), Sirmon et al. (1993), and Shannon (1991) have elaborated on the benefits of including the public in a democratic decision-making process. Sample (1993) provided a framework to help managers decide which general approach may be most appropriate under different situations, and Shindler and Neburka (1997) identified general guidelines for successful public involvement. Although these studies offer useful suggestions for improving the quality of public participation, they do not address techniques for analyzing public inputs.

Several procedures have been used to assess public preferences toward resource management. Knopp and Caldbeck (1990) gave respondents equal numbers of "credits" to allocate among land uses and implied that an allocation scheme consistent with the sum of the credits voted to each use might be appropriate for allocating resources. Shindler et al. (1993) used data from national and Oregon public surveys to assess broad-based public preferences for federal forest policy and

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opinions regarding public involvement in decision-making. Seventy-eight percent of the respondents supported increased public participation. The authors suggest using opinion surveys to measure respondents' levels of agreement or disagreement with policy statements. Shields et al. (1997) adapted methods in the field of decision theory to develop formal statements of stakeholder objectives. They recommended building objective hierarchies by querying each major stakeholder group. Quantifiable attributes were then selected to measure the extent to which an objective was met.

Although there is widespread agreement on the need to include the public in the decision-making process on national forests, there does not appear to be a generally accepted means for accomplishing the task. Germain and Floyd (1997) surveyed participants in the Forest Service's decision-making process and concluded that over 65% of the respondents were dissatisfied with the process. Although sincere efforts have been made to enhance the public involvement process, additional tools are needed (Jones et al. 1995, Thomas and Huke 1996).

Managers need a systematic and rational means to assess stakeholder preferences and analyze trade-offs. Because these decisions encompass a wide range of biophysical, financial, social, and moral variables, they are extremely complex and unyielding to traditional modes of analysis. The nonmarket nature of many objectives and differences in units of measure that characterize many natural resource benefits are particularly troublesome. This research explores the use of conjoint techniques to solicit and analyze public inputs to multiple objective decisions involving extramarket values. The empirical portion of this study addresses solicitation and assessment of public preferences for various levels of timber harvesting, wildlife habitats, and recreational opportunities on the Green Mountain National Forest (GMNF) in Vermont.

## The Green Mountain National Forest

The 145,700 ha GMNF makes up approximately 5% of the total land area and accounts for half of all public forestland in Vermont (USDA For. Serv. 1992). Its remoteness and relatively large size make the GMNF well suited to provide unique opportunities for backcountry recreation and wildlife habitats in a region characterized by nonindustrial private forests and high population density. Because public desires for forest-related benefits are intense and cannot be met simultaneously, a means for assessing preferences and values must be incorporated in the planning process.

National forest planning occurs on three broad levels: national, regional, and forest. The Forest Plan for the GMNF (USDA For. Serv. 1992) sets goals, objectives, standards, and guidelines that fit within broader direction specified at the national and regional levels. Forest goals are accomplished through management actions on Ranger Districts and subunits of these districts. Although public input and assessment of human values are important throughout the planning process, this study addresses public preferences for actions below the district level. Techniques and experience developed during this study will be useful in developing broader goals for the next Forest Plan.

The 7,500 ha study area, located on the Manchester Ranger District, includes two adjacent units known as Greendale and Utley. The area contains one developed campground (14 sites) and land classified in the Forest Plan as five different Management Areas (MAs). Three MAs include opportunities for roaded natural recreation and emphasize uneven-age silviculture, even-age silviculture, or winter habitat for deer. Another emphasizes opportunities for semiprimitive recreation while producing high-quality sawtimber by growing trees to an old age. The final MA is the White Rocks National Recreation Area, where the emphasis is on protecting wild values. Timber harvesting and roaded recreation are allowed, but restricted. Broad management prescriptions, standards, and guidelines are contained in the Forest Plan. Specific management actions need to be developed for the Greendale and Utley units. The goal of this research was to develop a procedure for assessing and analyzing public preferences and acceptable trade-offs for various levels of timber harvesting, wildlife habitats, and three recreational opportunities: hiking trails, snowmobile use, and off-road-vehicle (ORV) access.

Timber harvesting on the GMNF is controversial. Some argue against the environmental disturbance that accompanies the harvesting of wood products. Proponents argue that harvesting timber generates revenue for local and regional economies by creating jobs and cash payments for wood products exported from the area. It also is used to meet objectives related to wildlife habitat, silviculture, and recreation.

The Greendale/Utley area supports high species richness with a diverse late successional community of northern hardwoods, hemlock, and spruce. There are opportunities to enhance habitats for a variety of wildlife species through harvesting practices and the creation and maintenance of permanent openings, but it is not clear which species the public would like to see favored. If the public prefers species associated with early succession habitats (e.g., deer, rabbit), management can be tailored to meet these needs. Similarly, management can be structured to favor species associated with mature, contiguous habitats (e.g., pileated woodpecker, marten). For some respondents, the degree of openness created in the landscape also carries aesthetic meaning.

Recreational concerns center around opportunities for and potential conflicts between motorized and nonmotorized trail uses. There are opportunities to feature cultural resources (e.g., old roads, bridges, and farm sites) and to view wildlife (sightings of bear, moose, beaver, and birds are common) There are several opportunities to expand the system of hiking trails. Currently, 25.7 km of travelway are available for snowmobile use, and there is public interest in expanding the available travelway. However, some users are concerned that increased snowmobile access will disrupt other recreational activities and disturb wildlife. At present, ORVs are not permitted on travelways, but there is public interest in obtaining ORV access to the area, and several potential opportunities have been identified. Those in opposition cite ecological damage and disturbances to wildlife or other recreationists as reasons to deny ORV access.

## Conjoint Analysis

Conjoint analysis, a technique for measuring psychological judgments, is used in marketing research to measure consumer preferences (Green et al. 1988). In conjoint studies, respondents make choices between alternative products or scenarios displaying varying levels of selected attributes. For example, when studying consumer preferences for features of station wagons, respondents might be asked to choose between sample vehicles that vary in attributes such as cargo space, warranty length, gas mileage, horsepower, and country of manufacture. The objective is to decompose a set of factorially designed stimuli or attributes so that the utility of each attribute can be inferred from the respondents' overall evaluations. These data, which outline a respondent's preferences or the trade-offs he or she is willing to make, can be used to solve for the partial utilities for each attribute that are imputed from the overall trade-offs. These partial utilities, or part worths, as they are sometimes called, can be combined to estimate relative preferences for any combination of attribute levels. Thus, the analyst obtains high leverage between the options actually evaluated by respondents and those that can be analyzed after the evaluation.

Conjoint techniques are well suited for soliciting and analyzing the preferences of stakeholders in environmental decisions. These decisions frequently entail trade-offs between costs and benefits that are not represented efficiently in market transactions. For example, Opaluch et al. (1993) described an approach that used paired comparisons to rank potential noxious facility sites in terms of social impacts. Asking respondents to make choices between alternatives mimics the real choices that managers must make and shows stakeholders the consequences of their choices.

Choice experiments can be designed and analyzed in many ways. Respondents may be asked to reveal their preferences by choosing one of two or more options, ranking several options, or assigning numerical ratings to each option. Numerical ratings provide the most information but also place the greatest cognitive demands on respondents. Green (1974), Green and Srinivasan (1978), Louviere and Woodworth (1983), and Louviere (1988) provide information on experimental design in the context of conjoint analysis.

## Analytical Model

When presented with a set of alternatives, individuals are assumed to make choices that maximize their utility or satisfaction. The utility that the $i$th individual derives from the choice of the $j$th alternative ($U_{ij}$) can be represented as:

$$U_{ij} = X'_{ij}\beta^* + e_{ij} \tag{1}$$

where $X_{ij}$ is a vector of variables representing values for each of $M$ factors or attributes of the $j$th alternative to the $i$th individual, $\beta^*$ 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 of the $J$ alternatives is not observed but an ordinal ranking ($Y_{ij}$) is observed that corresponds to the order of his or her underlying utilities. The probability of alternative 1 being ranked above other alternatives is:

$$\begin{aligned} P_{i1} &= \Pr(U_{i1} > U_{i2} \text{ and } U_{i1} > U_{i3} \ldots \text{ and } U_{i1} > U_{iJ}) \\ &= \Pr[(e_{i2} - e_{i1}) < (X'_{i1}\beta^* - X'_{i1}\beta^*) \\ &\quad \ldots \text{ and } (e_{iJ} - e_{i1}) < (X'_{i1}\beta^* - X'_{iJ}\beta^*)] \end{aligned} \tag{2}$$

Similar expressions hold for each of the remaining alternatives being chosen next in the choice set, and the $P_{ij}$'s become well-defined probabilities once a joint density function is chosen for the $e_{ij}$ (Judge et al. 1985).

McKelvey and Zavoina (1975) developed a polychotomous probit model to analyze ordinal level dependent variables. They assume that the $e_{ij}$'s are distributed normally with mean 0 (the variance is standardized to unity), and that the observed variable ($Y_{ij}$, the ranks for the $J$ alternatives) is related to the true unobserved utilities ($U_{ij}$) in the following way:

$$\begin{aligned} Y_{ij} &= 0 \text{ if } U_{ij} \le \mu_{i1}, \\ Y_{ij} &= 1 \text{ if } \mu_{i1} < U_{ij} \le \mu_{i2}, \ldots \\ Y_{ij} &= J-1 \text{ if } U_{ij} > \mu_{iJ-1} \end{aligned} \tag{3}$$

The $\mu_{ik}$'s define the boundaries of the intervals for the unobserved utilities that correspond to the observed ordinal response. Since the $\mu$'s are free parameters, there is no significance to the unit distance between the set of observed values of $Y$; they merely provide the ranking.

Estimates are obtained by maximum likelihood, and the probabilities entering the log-likelihood function are the probabilities that the observed ranks ($Y_{ij}$'s) fall within the $J$ ranges defined by $J + 1$ $\mu$'s. The parameters to be estimated are $J - 2$ $\mu$'s plus the $\beta$ vector; $\mu_0$ and $\mu_J$ are assumed to be negative and positive infinity, respectively, and $\mu_1$ is normalized to 0. McKelvey and Zavoina (1975) describe the model and maximum likelihood estimators in greater detail.

In the polychotomous probit model the estimated value ($X'_{ij}\beta$) for an observation determines the position of the mean of the distribution of response categories over the underlying scale as shown in Figure 1. The $\mu$'s delineate ranges in the unobserved underlying variable (utility) that correspond to the observed response categories. The estimated probability that a response will fall in each category or rank in the case under consideration is measured by the area under the normal standard density curve [$f(X'_{ij}\beta)$] and bounded by the respective $\mu$'s. These probabilities can be computed using the estimated model parameters:

$$\begin{aligned} \Pr(Y_j = k-1) &= \Pr(U_j \text{ is in the } k\text{th range}) \\ &= F(\mu_k - X'_j\beta) - F(\mu_{k-1} - X'_j\beta) \end{aligned} \tag{4}$$

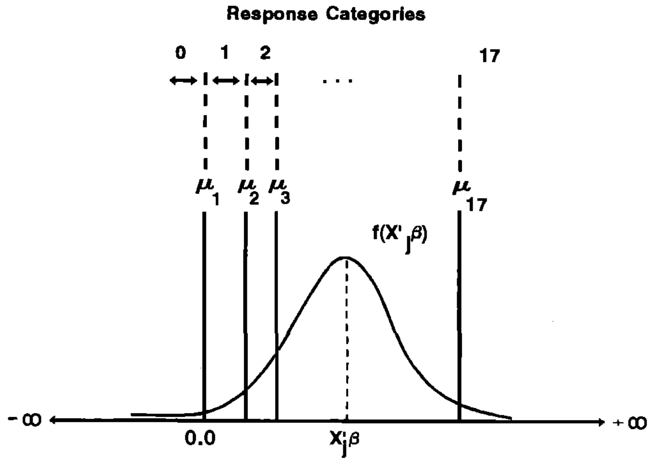


**Figure 1. Estimation of the probabilities of response categories for the ordered probit model.**

where $k$ indexes the rankings and $F(\bullet)$ is the cumulative standard density function, assumed normal for the probit specification. Thus, the effect of a discrete change in the level of the $n$th independent variable ($x_{nj}$) on the estimated probability that a response will fall within each of the categories (ranks) can be calculated by substituting the estimated parameters ($\beta$ and $\mu$'s) into Equation (4). In probit analysis the estimated coefficients ($\beta$) represent the effect of a unit change in an independent variable on underlying scale given by $X_j'\beta$. Graphically, this is shown as a shift in the distribution of responses over the underlying scale. The magnitude of that change on the probability of a particular response occurring will depend on the original position as determined by all the estimated parameters and associated variables.

## Survey Design

A conjoint ranking survey was designed to solicit preferences for five forest-related factors or attributes: timber, wildlife habitat, hiking trails, snowmobile use, and ORV access. Three levels covering the range of reasonable options for the Greendale and Utley units were selected for each attribute (Table 1). Eighteen alternatives, each depicting a unique bundle of attribute levels, were chosen using an orthogonal design that allows estimation of all linear and quadratic main effect components over the entire range of possible attribute combinations, with the least number of trials.

Although in some cases the attribute levels coincide with on-the-ground alternatives, they also are indicators for broad forest-related values. For example, changes in the distance of travelway available for snowmobile use also may represent perceived changes in the overall snowmobile experience, congestion in parking areas, noise levels, chances for sighting wildlife, tourism revenues for the region, use conflict on trails, and other values perceived by respondents. Similarly, differences in the number and size of openings in the landscape referenced within the wildlife attribute carry aesthetic meaning as well.

Respondents were given an explanation describing concerns and alternatives for the Greendale/Utley area as well as an overview of the nature and purpose of the conjoint study. Respondents were provided with a brief verbal explanation of the attributes and levels shown in Table 1 and given the opportunity to ask questions or discuss their concerns. Additional information, such as expected volume of timber harvests for each level of the timber attribute, and lists of species favored for each level of the wildlife attribute, was provided Large overlay maps were used to illustrate locations of forest types, prospective harvests and silvicultural treatments, travelways and other pertinent information. Respondents then ranked 18 sample cards, each representing a unique alternative depicted by a bundle of forest-related attribute or factor levels for the Greendale/Utley area. Two sample cards are shown in Table 2. Respondents also completed a series of attitudinal and demographic questions.

The survey was administered by USDA Forest Service personnel during public meetings. Two of these sessions were held in conjunction with bordering town functions (the annual Landgrove town meeting and a Planning Commission meeting in Weston). Other sessions were held in or near

**Table 1. A list of the choice attributes and levels used to describe alternatives.**

| Attribute | Levels |
|---|---|
| Timber | 1 Do not harvest timber. |
| | 2 Harvest timber on 5–10% of the planning area. |
| | 3 Harvest timber on 15–20% of the planning area. |
| Wildlife | 1 Favor wildlife preferring contiguous unbroken forests. |
| | 2 Favor wildlife preferring a mix of young forests and contiguous unbroken forests. |
| | 3 Favor wildlife preferring open lands and young forests. |
| Hiking trails | 1 Maintain existing hiking opportunities. |
| | 2 Extend the hiking trail system to include 3.2[1] additional kilometers. |
| | 3 Extend the hiking trail system to include 9.7[1] additional kilometers. |
| Winter motorized | 1 Do not permit snowmobile use. |
| | 2 Maintain the existing 25.7[1] kilometers of travelway for snowmobile use. |
| | 3 Extend the travelway available for snowmobile use to 37 kilometers. |
| Summer motorized | 1 Do not permit ORVs on travelways. |
| (e.g., 3- and 4-wheel ORVs, motorized trail bikes). | 2 Provide approximately 8 kilometers of travelway for ORV use. |
| | 3 Provide approximately 12.9[1] kilometers of travelway for ORV use. |

[1] Decimal values result from converting the English units used in the survey to the metric units reported here.

**Table 2. Two of the 18 cards used to depict alternatives in the conjoint ranking survey.**

| Alternative #8 | Alternative #14 |
|---|---|
| Harvest timber on 15–20% of the planning area.<br>Favor wildlife preferring a mix of young forests and contiguous unbroken forests.<br>Extend the hiking trail system to include 9.7[1] additional kilometers of trails.<br>Maintain the existing 25.7[1] kilometers of travelway available for snowmobile use.<br>Do not permit ORVs on travelways.<br><br>RANK __ | Harvest timber on 5–10% of the planning area.<br>Favor wildlife preferring a mix of young forests and contiguous unbroken forests.<br>Extend the hiking trail system to include 9.7[1] additional kilometers of trails.<br>Do not permit snowmobile use.<br>Provide approximately 8 kilometers of travelway for ORV use.<br><br>RANK __ |

[1] Decimal values result from converting the English units used in the survey to the metric units reported here.

Burlington, the largest population center in Vermont, located about 160 km from the planning area. Those who were unable to attend one of the scheduled meetings were given the opportunity to complete the survey at the local district office. Although efforts were made to attain a broad group of respondents, we did not attempt to achieve representation from every interested group or to select a random sample of respondents to represent the general public. The goal for this portion of the GMNF's outreach effort was to solicit and analyze the preferences of people who were interested in and willing to participate in the management decisions for the Greendale/Utley area. The model discussed in the next section applies to the population of interested and concerned citizens that is characterized by this sample of respondents.

An ordered probit model was used to analyze data obtained from 76 respondents. Each respondent ranked 18 alternatives providing 1,368 observed preferences. The dependent variable is the ordinal ranking of the alternatives, which was coded from 0 to 17; higher scores were associated with greater utility. The attribute levels (1, 2, 3 in Table 1) for the independent variables were coded, respectively, –1, 0, 1 for the linear form and 1, –2, 1 for the quadratic form. This coding scheme maintains the ordinal relationship for the linear term and provides for an orthogonal contrast with the quadratic term and constant.

## Results and Discussion

In general, respondents were fairly affluent. The average level of education was 16 yr, indicating completion of college, and the average total family income was within the range of $50,000–$75,000 per year. Sixty-two percent of the respondents were men, and the average age was 48 for all respondents. Nearly all of the respondents were Vermont residents; on average, they had lived in the state for 23 yr.

General inferences about respondent preferences concerning each attribute can be made from the results in Table 3. The coefficients relate to the orthogonal contrasts and coding of the dependent variable outlined in the previous section. The nature of the overall relationship depends on the signs and relative magnitudes of the estimated coefficients for both the linear and quadratic contrasts. Inferences will be discussed, first with respect to individual attributes and then to overall preference for the bundles of attribute levels that comprise alternatives.

**Table 3. Ordered probit parameters for a multi-attribute conjoint ranking survey ($N$ = 1,368).**

| Variable | Coefficient | Std. Err. | $t$-ratio |
|---|---|---|---|
| Constant | 1.8105* | 0.0576 | 31.42 |
| Linear effects | | | |
| Timber | 0.4133* | 0.0351 | 11.77 |
| Wildlife | –0.0290 | 0.0349 | –0.83 |
| Hiking | 0.0633*** | 0.0355 | 1.78 |
| Snowmobile | –0.0499 | 0.0351 | –1.42 |
| ORV access | –0.3719* | 0.0347 | –10.73 |
| Quadratic effects | | | |
| Timber | –0.1791* | 0.0215 | –8.36 |
| Wildlife | –0.0435** | 0.0204 | –2.13 |
| Hiking | 0.0161 | 0.0200 | 0.80 |
| Snowmobile | –0.0729* | 0.0210 | –3.48 |
| ORV access | 0.0093 | 0.0216 | 0.43 |
| Boundary parameters | | | |
| $\mu_1$ | 0.0000 | | |
| $\mu_2$ | 0.4016 | | |
| $\mu_3$ | 0.6880 | | |
| $\mu_4$ | 0.9220 | | |
| $\mu_5$ | 1.1263 | | |
| $\mu_6$ | 1.3138 | | |
| $\mu_7$ | 1.4891 | | |
| $\mu_8$ | 1.6558 | | |
| $\mu_9$ | 1.8179 | | |
| $\mu_{10}$ | 1.9800 | | |
| $\mu_{11}$ | 2.1453 | | |
| $\mu_{12}$ | 2.3153 | | |
| $\mu_{13}$ | 2.4934 | | |
| $\mu_{14}$ | 2.6884 | | |
| $\mu_{15}$ | 2.9138 | | |
| $\mu_{16}$ | 3.1967 | | |
| $\mu_{17}$ | 3.6142 | | |

* Significant at the 1% level.
** Significant at the 5% level.
*** Significant at the 10% level.

### *Respondent Preferences for Individual Attributes*

The positive sign for the linear contrast for the timber attribute indicates that increased timber harvesting will result in a higher estimated probability of a response falling within the ranges associated with greater utility. However, the significance of the quadratic timber contrast indicates this relationship is nonlinear. The estimated negative sign for the quadratic contrast indicates that respondents associate decreasing marginal benefits with increased harvesting (Figure 2a). Respondents supported timber harvesting activities strongly but preferred level 2 slightly more than level 3.

The coefficient for the linear contrast for the wildlife variable was not statistically different from zero. However, the significance of the quadratic contrast for the wildlife variable indicates that respondents favored a mixture of young, more open, and contiguous unbroken forests over either extreme (Figure 2b). These results support those for timber harvesting; respondents did not favor widespread harvesting or an open landscape, nor did they favor a contiguous unbroken forest devoid of harvesting.

Respondents showed a weak preference for extending hiking opportunities. The coefficient for the linear contrast for the hiking variable was positive but significant only at the 10% level. Although over 90% of the respondents hike, they appeared to key their rankings on other attributes. Numerous hiking opportunities already exist in this area, as well as in the surrounding region. Respondents appeared to be more concerned about changes in alternative trail use than on extending the trail system. They also may perceive that less impact would result from the relatively small changes reflected in the levels for this attribute.

Although there has been conflict between snowmobilers and other winter trail users in the past, respondents appeared to recognize snowmobiling as a valid use of the area. The significance of the quadratic contrast for this attribute indicates that respondents preferred maintaining the existing snowmobile trails over either closing all the travelways or extending the network (Figure 2c). This is interesting, given

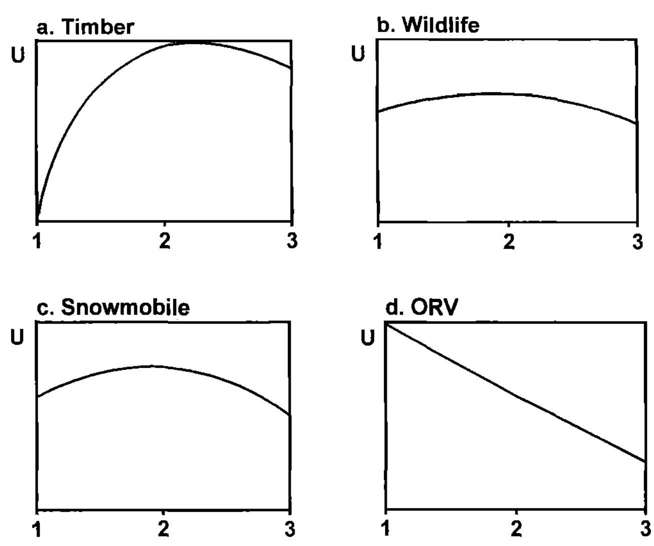


**Figure 2. Partial utilities by attribute and level (all other attributes held constant).**

that only 8% of the respondents use snowmobiles while participation was quite high for cross country skiing (84%), wildlife viewing (73%), and bird watching (55%), activities that could conflict with snowmobile use.

Participation in ORV use was also low among respondents (7%), but in this case they did not feel that this was an appropriate use for this area. The estimated coefficient for the linear contrast for the ORV attribute was negative and highly significant (Figure 2d). Utility, as expressed through the ranking of the alternatives, clearly declined with increased ORV access.

### *Optimal Mix of Attribute Levels*

The orthogonal sample design used to select the alternatives that were displayed to the public allows estimation over the entire range of 243 ($3^5$) possible alternatives. The optimal mix of attribute levels predicted by the model provides for harvesting timber on 5–10% of the area (level 2), a mix of young and unbroken forest (level 2), extending the hiking trails (level 3), maintaining the existing snowmobile network (level 2), and no ORV access to the area (level 1). Except for their bias against ORV access to the area, respondents favored moderate levels of the other attributes.

Although respondents did not rank an alternative that matched the optimal alternative predicted by the model, they ranked Alternative 8 (Table 2) highest among the 18 alternatives that they were given. This alternative provides for the highest feasible level of harvesting (15–20% of the area) but otherwise was the same as the optimal mix of attribute levels predicted by the model. Nearly one-quarter of the respondents ranked it first, while two-thirds of the respondents ranked it within the top third.

### *Effect of Discrete Changes in Attribute Levels*

Interpreting the estimated parameters for the polychotomous probit model is different than interpreting standard regression parameters. The combined effect of the estimated parameters associated with the linear and quadratic effects for each independent variable represent the effect of a discrete change in that variable on the underlying scale given by $X_{ij}'\beta$. Values for $\mu_2$ to $\mu_{17}$, which were estimated in addition to the parameters associated with the attributes ($\beta$ vector), are shown in Table 3. As discussed previously, the $\mu$'s delineate ranges in the unobserved underlying variable (utility) that correspond to the observed response categories (ranks). The estimated value of $X_{ij}'\beta$ for any given combination of attribute levels determines the position of the distribution of ranks over the underlying scale. The estimated probability that a response will fall within each response category is depicted in Figure 1 as the area under the $f(X_{ij}'\beta))$ curve and bounded by the respective $\mu$'s. These probabilities can be computed using Equation (4). Because the probabilities across the ranks must sum to 1, the effect of a change in an independent variable is to increase the estimated probability that an alternative will fall within some response categories while decreasing the probability of falling within others. The magnitude of the estimated changes in probabilities depends on the values for all the coefficients as well as the values of the other independent variables at which the change is evaluated.

The expected change in the probability of an alternative being ranked in a particular category resulting from a discrete change in an independent variable can be calculated using Equation (4). For example, varying the timber attribute over levels 1, 2, and 3 while holding the other attributes constant at the middle levels yields estimated probabilities that this alternative will be ranked within the top 3 of 0.065, 0.287, and 0.246, respectively. The probability of it being ranked within the lowest 3 was 0.238, 0.048, and 0.062, respectively, for the 3 levels of timber harvesting. The magnitude of change is greatest between levels 1 and 2, illustrating the decreasing marginal benefits of timber harvesting discussed previously. Similar calculations can be performed for any change in individual attributes or combinations of attributes of interest to the analyst. For example, one could calculate the estimated probability that a given alternative would be ranked within the highest or lowest quintile.

### *Trade-Offs*

The marginal rate of substitution (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 trade-off of one attribute for another is determined by the ratio of the marginal responses. The procedure for computing the MRS is outlined in the Appendix.

General inferences concerning acceptable trade-offs among attributes cannot be made when the underlying relationships are nonlinear as they are for several of the attributes. Each solution is valid only for a particular mix of attribute levels. Although analytically more complicated than a linear specification the nonlinear specification is intuitively appealing; it is expected that one's willingness to trade among features would depend on the present levels of these features.

The MRS can be useful when computed at points of interest to managers. For example, suppose budget constraints prevent attaining the optimal bundle of attribute levels and that all attributes are at their optimal level except for the wildlife and snowmobile attributes, both of which are at level 1. A small increase in funding could be used to create openings in the forest to benefit certain species of wildlife or to open some travelway for snowmobiles. Either activity would be an improvement. The MRS (snowmobile for wildlife) is 2.1, computed using Equation (9) in the Appendix. That is, the marginal increase in utility is about twice as great for an increase in snowmobile access versus openings for wildlife, when evaluated at level 1 for each attribute.

### *Model Fit*

There is often concern in conjoint studies that inferences drawn from the model will reflect the preferences of the respondents adequately. Marketing researchers do not want to recommend a product that pleases an "average," but possibly nonexistent, consumer. Likewise, resource managers will want to know whether estimates depict a consensus of respondent preferences or a midpoint between opposing preferences. In the latter case an underlying assumption of the ordered probit model, that the error term ($e_{ij}$) is distributed normally, may not be met.

Evaluating the overall fit of the model is not a straightforward task. McKelvey and Zavoina (1975) developed a procedure to calculate a pseudo-$R^2$ similar to the $R^2$ or coefficient of determination in regression analysis. Since residuals are not observed for probability models, they estimated the residual and total sums of squares. Since little is known about the distribution of this and other estimates of $R^2$ for probability models, they and others (e.g., Aldrich and Nelson 1984) recommend extreme caution when using summary measures to evaluate these models.

An alternate and intuitively appealing method for evaluating the appropriateness of the model is to compare the frequency distribution of the observed ranks for each alternative with the distribution that is expected under the model assumptions. Equation (4) can be used to determine the estimated probabilities that an alternative will be ranked in each of the 18 categories. These proportions multiplied by the number of respondents yields an expected frequency distribution of ranks for each alternative that can be compared with the observed frequency distributions, and tested for goodness-of-fit using a chi-squared test. Statistically significant differences between the observed and expected distributions of responses for an alternative would provide evidence that the observed responses were not distributed normally with unit variance about the expected score ( $X_j'\beta$ ) for that alternative. This procedure was performed for each of the 18 sample alternatives. None of the chi-squared statistics were significant at the 5% level, which can be taken as lack of evidence that there is a failure in the assumption of a normally distributed error term. This viewpoint is corroborated by the large number of respondents that ranked the alternative that most closely matched the optimal mix of features estimated by the model highly.

## Conclusions

Public resource managers and planners need a means to solicit and analyze human preferences and values so they can make effective multiple objective decisions that involve trade-offs between costs and benefits that are not efficiently represented in market transactions. Conjoint techniques are well suited for this task. Asking respondents to make choices between alternatives mimics the decisions that managers must make and provides information on the relative values and acceptability of trade-offs involved in selecting an appropriate mix of outputs. A conjoint ranking survey was used to solicit public preferences for alternatives that included various levels of timber harvesting, wildlife habitats, hiking trails, snowmobile use, and ORV access on the GMNF. Seventy-six respondents completed the survey during public involvement sessions.

An ordered probit model was used to estimate linear and quadratic main effects from the public responses. Respondents clearly supported timber harvesting, but preferred the midlevel of timber harvesting slightly more than the highest of three levels. Complementing their support for moderate timber harvesting respondents preferred a mixture of young open and contiguous unbroken forest over either extreme.

Although most of the respondents hiked, they generally weighted other attributes more heavily in their rankings and seemed more concerned about alternate trail uses. Even though few of those surveyed used snowmobiles, they recognized snowmobiling as a valid use of the area. However, respondents were not tolerant of opening the area to ORVs and registered this sentiment clearly in their rankings.

The optimal mix of attribute levels estimated by the model was the midlevel for timber harvesting, a mix of open and contiguous unbroken forest, extending hiking trails, maintaining the existing snowmobile network, and not permitting ORV use in the area. The preferred mix was least sensitive to changes in the level of maintained hiking trails. Changes in overall preference resulting from adjustments to any of the other attribute levels, as well as the marginal rates of substitution or acceptable trade-offs among attributes, can be assessed using the results and analytical techniques discussed previously.

Generally, respondents supported multiple objective management for this area. These results differ significantly from the relatively extreme demands that often are articulated by special interest groups and some individuals. Calls to ban timber harvesting or snowmobiling from an area set the stage for opposite demands from those that benefit from these activities. Managers often end up in a lose-lose situation, caught between the vocal and seemingly unyielding demands of opposing stakeholders. Conjoint surveys and the ensuing analyses provide a means for sifting through the relative values placed on various benefits and for assessing preferences for entire bundles of attributes.

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## APPENDIX: Marginal Rates of Substitution

The marginal rate of substitution (MRS) of one attribute for another is determined by the ratio of the marginal responses computed while holding total utility constant. For the ordered probit model this is accomplished by computing the partial differentials of Equation (4) with respect to the attributes (factors) of interest. To adapt the analyses to the model under consideration, $\beta$ must include both linear ($\delta$) and quadratic ($\gamma$) effects and the $x_{mj}$'s must be transformed to adjust for the coding scheme that was used to capture orthogonal contrasts. The $m$ subscript indicates the attribute (e.g., timber, wildlife habitat), and the $j$ indicates the alternative being evaluated. The functions $x_{mj} - 2$ for the linear component and $3x_{mj}^2 - 12x_{mj} + 10$ for the quadratic component can be used to transform the original attribute levels 1, 2, 3 (the $x_{mj}$'s) to the orthogonal contrasts used in the analyses (–1, 0, 1 for the linear contrast and 1, –2, 1 for the quadratic contrast). Substituting in Equation (4) yields:

$$\begin{aligned} \Pr(Y_j &= k-1) \\ &= F[\mu_k - \left( \sum_{m=0}^{5} (x_{mj} - 2)\delta_m + \sum_{m=0}^{5} (3x_{mj}^2 - 12x_{mj} + 10)\gamma_m \right)] \qquad (5) \\ &- F[\mu_{k-1} - \left( \sum_{m=0}^{5} (x_{mj} - 2)\delta_m + \sum_{m=0}^{5} (3x_{mj}^2 - 12x_{mj} + 10)\gamma_m \right)] \end{aligned}$$

Differentiating with respect to the level of the $n$th attribute yields:

$$\partial P / \partial x_{nj}$$
$$= f[\mu_k - \left(\sum_{m=0}^{5}(x_{mj} - 2)\delta_m + \sum_{m=0}^{5}(3x_{mj}^2 - 12x_{mj} + 10)\gamma_m\right)]$$
$$[\delta_n + (6x_{nj} - 12)\gamma_n] \tag{6}$$
$$- f[\mu_{k-1} - \left(\sum_{m=0}^{5}(x_{mj} - 2)\delta_m + \sum_{m=0}^{5}(3x_{mj}^2 - 12x_{mj} + 10)\gamma_m\right)]$$
$$[\delta_n + (6x_{nj} - 12)\gamma_n]$$

where F(•) is the cumulative distribution function and f(•) is the probability density function of the normal distribution.

Letting $W$ denote:

$$f[\mu_k - \left(\sum_{m=0}^{5}(x_{mj} - 2)\delta_m + \sum_{m=0}^{5}(3x_{mj}^2 - 12x_{mj} + 10)\gamma_m\right)]$$
$$- f[\mu_{k-1} - \left(\sum_{m=0}^{5}(x_{mj} - 2)\delta_m + \sum_{m=0}^{5}(3x_{mj}^2 - 12x_{mj} + 10)\gamma_m\right)] \tag{7}$$
$$\partial P / \partial x_{nj} = [\delta_{nj} + (6x_{nj} - 12)\gamma_n]W$$

Then

$$MRS(\text{attribute } l \text{ for } n) =$$
$$\frac{\partial P / \partial x_{lj}}{\partial P / \partial x_{nj}} = \frac{[\delta_{lj} + (6x_{lj} - 12)\gamma_l]W}{[\delta_{nj} + (6_{nj} - 12)\gamma_n]W} \tag{8}$$

which simplifies to

$$MRS(\text{attribute } l \text{ for } n) =$$
$$\frac{\partial P / \partial x_{lj}}{\partial P / \partial x_{nj}} = \frac{[\delta_{lj} + (6x_{lj} - 12)\gamma_l]}{[\delta_{nj} + (6_{nj} - 12)\gamma_n]} \tag{9}$$