RECLAMATION

Managing Water in the West

Technical Memorandum Number EC 2008-03

Introduction to Conjoint Analysis for Valuing Ecosystem Amenities

U.S. Department of the Interior
Bureau of Reclamation

February 2008

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The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Introduction to Conjoint Analysis for Valuing Ecosystem Amenities

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Purpose

The purpose of this document is to convey a conceptual and analytic understanding of the conjoint analysis (CA) methodology used for valuing ecosystem amenities. An example application is described and solved in a step-by-step fashion. While by no means an exhaustive treatment of the subject, some of the difficulties and associated pitfalls are described. A number of useful references are furnished for further study.

What is Conjoint Analysis?

In recent years, conjoint analysis (CA) has been employed to estimate the net economic value of natural resource amenities. This approach has its origins in business marketing research and there are many applications in this context. Conjoint analysis is based on a primary survey of individuals utilizing a carefully designed survey instrument. Respondents are presented with different hypothetical situations, described using their characteristics or attributes. and asked either to rank them or choose between them. Using the resultant survey data, the probability that an individual will rank or choose any particular scenario is then estimated. The consumer surplus or net economic value of the amenity can then be derived.

Synonyms

There are an amazingly large number of terms for conjoint analysis. The usage of these terms seems to vary by discipline, with the context and nature of the application. The vast majority of business and marketing applications employ the term conjoint analysis while economic studies use a variety of alternate descriptors. Commonly encountered synonyms for conjoint analysis include the following terms; contingent ranking (CR), attribute-based methods (ABMs), stated preference choice experiments (SPCEs) and choice-based experiments (CBEs).

Because of economist’s focus on economic welfare and willingness to pay (WTP) measures, Holmes and Adamowizc (2003) suggest their use of attribute-based methods differs from other applications of conjoint analysis. Their view is hardly universal however and the use of synonyms remains commonplace and confusing.

Nonmarket Goods

Values for goods traded in the market are called market values and are the traditional measure of value associated with changes in water resource management. Familiar water resource examples are irrigation benefits and hydropower benefits. Values for goods which are not traded in the market (and thus not observable) are called nonmarket values. These may include changes in the quantity and quality of recreation or changes in the intrinsic value of a resource.

Recreation use is a commonly cited example of a nonmarket good. Certain types of recreation uses, such as fishing and hunting, are termed consumptive uses. A characteristic of consumptive use is that once a good is used by one individual, it is unavailable for use by another individual. For example if a recreational angler catches and keeps a fish, that fish is unavailable for other anglers to catch.

Some recreation use activities, such as hiking, are termed nonconsumptive uses. Hiking, bird watching, wildlife viewing and similar activities do not require the consumption of a resource. In the absence of crowding, other individuals can use or share in the use of the resource without diminishing it.

Nonuse values are a special case in which the nonmarket good is the status of the natural or physical environment. Nonusers, or individuals who never visit or otherwise use a natural resource may nonetheless be affected by changes in its status or quality. Monetary expression of their preferences for these resources is known as nonuse or passive-use economic value. Economists also use the terms passive-use value and intrinsic value to describe these preferences.

Stated and Revealed Preference

There are two major classes of techniques for measuring the value of nonmarket goods. These are the revealed preference approach and the stated preference approach. Revealed preference approaches are based on the observed behavior of consumers. The observed behaviors reflect the decisions which people make regarding activities that utilize or are affected by an environmental amenity. Reveal preference studies typically focus on measuring economic use value. In contrast, stated preference methods elicit values directly from individuals, through survey methods. The stated preference methods are suitable for measuring both direct use and nonuse or passive use values.

Some Definitions

As with any topic, there is a unique vocabulary associated with conjoint analysis. Some commonly encountered terms are defined and a brief explanation is provided below.

Attribute

An *attribute* is characteristic or feature of a good which is of importance to consumers when they make expenditure decisions. In the case of a vehicle purchase decision, for example, pertinent attributes may be such things as the price, the color, the number of doors, the size of the engine, off-road capability and so forth. For a natural resource amenity, characteristics such as the cost, the level of crowding, the catch rate, available access, and the view-shed in the surrounding area may be pertinent attributes.

Level

Attributes can be numerically described using *levels*. In the case of a vehicle, for example, the size of the engine can be described using horsepower. For a natural resource amenity, such as a fishing experience, the catch rate can be characterized by the number of fish of a certain size which are landed per unit time.

Profile

A short description of a hypothetical good using its attributes and the levels of each of those attributes is known as a *profile*. Synonyms include the terms alternative and treatment combination. Since many conjoint experiments are one-at-a-time choices, the term profile is more widely employed.

Orthogonal

Statistically, two vectors are said to be orthogonal or uncorrelated if their inner product is the zero vector (or matrix). This indicates the cross correlation of each element in the two vectors is zero. Typically, conjoint experiments are constructed to ensure the levels of their attributes across profiles are orthogonal.

Origins and History

Conjoint analysis is typically thought of as arising from business marketing research. As some authors point out though, marketing researchers borrowed heavily from earlier economics research. This includes the discrete choice econometrics work by Daniel McFadden, the 2000 Nobel Prize winner in economics (Orme 2006).

In the business marketing context, students are often taught the term “conjoint” refers to respondents evaluating features of products or services, “CONsidered JOINTly” (Orme 2006). Several authors have suggested the term actually derives from the verb “to conjoin” meaning “joined together” (Orme 2006).

Conjoint measurement methods were first described in the mathematical psychology literature by Luce and Tukey (1964). Drawing on their work, Paul Green applied the concept to complex purchasing decisions and the prediction of buyer behavior. He and coauthor Rao subsequently published what is recognized by most authors to be the seminal article on the topic of conjoint analysis (Green and Rao 1971).

Early conjoint analyses were based on the so-called “full-profile” approach. These were typically implemented by using specially designed conjoint card decks. Each card in the deck described a product profile. Respondents were required to sort the deck from the most desirable profile to the least desirable profile. The size of the deck reflected an orthogonal design and increased rapidly with the number of attributes and the number of levels. For practical reasons, this limited the number of attributes and levels which could be investigated.

Researchers soon found that better response data could be obtained by asking respondents to rate (on a scale of, for example, 1 to 10) the desirability of each card.

Richard Johnson (1974) invented a clever method of making pairwise trade-offs which is used in experiments to this day. This allowed respondents to focus on two attributes at a time. Johnson formed one of the preeminent firms in this field, Sawtooth Software, and went on to develop a process called adaptive conjoint analysis (ACA). The ACA approach dynamically narrows the number of conjoint questions posed to a respondent based on the pattern of their previous responses.

In the late 1980s, the evolution of conjoint analysis drew upon the emerging field of discrete choice analysis pioneered by McFadden and others. Discrete choice methods allow conjoint questions to be constructed in a manner that is more realistic and natural to respondents. Although the associated econometric methods are much more complex, it can allow for a more rigorous modeling of attribute interactions.

More comprehensive and informative accounts of the history and evolution of conjoint analysis can be found in Orme (2006), Holmes and Adamowizc (2003) and other sources.

Steps in a CA Study

Although there are many variations in approach, a number of practitioners seem to agree on an eight-step approach to conjoint analysis. These eight steps are described below.

Characterize the Problem

The first step in undertaking a conjoint analysis is identifying the problem and characterizing its salient features. For a traditional marketing study, this might include identifying the focus of the exercise in terms of product features, packaging or price and how that might effect market share or total product purchases. In the natural resource economics context, the analyst should identify the geographic scope and the range of economic values potentially affected by changes in amenity services.

Identify the Relevant Population

An important aspect of any primary survey exercise is the identification of the population which could be affected by the proposed management action. The identified relevant population forms the sample frame which should be targeted by the survey effort. For less well known but locally important resources, contemplated management changes may affect only a small and localized stakeholder group. In such cases, survey administration may well be limited to these identifiable groups. Other contemplated management actions may affect unique and irreplaceable resources of national and international significance. Yellowstone National Park is one example of such a resource. Yellowstone National Park was created in order to preserve its unique natural characteristics, thermal features, landforms and wildlife populations. A management action which could potentially impact the Yellowstone ecosystem may affect a large number of stakeholder groups across the United States and elsewhere. In this case, the relevant population is likely to be, at a minimum, the population of the United States.

Attributes and Levels

After the nature of the decision problem has been identified, the attributes pertinent to the decision need to be determined. The researcher will need to identify the most important attributes shaping consumer decisions about the good. For example, if a fishing experience is the good, the researcher will need to identify the attributes of that experience which affect consumer choice. These attributes may include access, cost, catch rate, species caught, crowding and a host of other characteristics. Identification of the most important of these factors concurrently with their relevant levels is quite difficult and resource intensive. In practice, expert opinion, focus groups and survey pre-tests are extensively employed for this purpose.

Setting appropriate levels for each attribute requires experience and professional judgment. For discontinuous attributes such as color, the attribute levels might be blue, red, green and black. For continuous attributes such as price, the attribute levels should be specific points like $10, $100 and $500. There is balance between too few options and too many. The range of levels should encompass the bounds of realistic price levels and span the range of possible policy outcomes.

Experimental Design

Identification of an appropriate experimental design is critically important to survey development and model estimation. Three experimental designs are in common use today. These are the full factorial design, the fractional factorial design and the randomized design.

Full Factorial

A factorial experimental design combines every level of each attribute with every level of all other attributes. Depending on the author, full factorial designs may also be called, "full profile" designs. A practical problem with a full factorial design is that a large number of profiles are generated as the number of attributes and levels increases. In addition, some combinations of attributes and levels may not be logical or realistic.

If an experiment is constructed with three attributes (n=3) each of which has two levels (L=2), the number of profiles (np) generated for a full factorial design is $np=L^n$ or np=8 profiles. Clearly, as the number of attributes and levels of each of those attributes increase, the number of profiles can potentially become unwieldy and impractical.

There are a number of statistical and economic advantages of a full factorial experimental design. In a full factorial design, all of the attributes are orthogonal or independent of each other. This allows the econometric identification of all of the "main" and "interaction" effects. The "main" effect is the difference between the average (mean) response to each attribute level and the overall average (or "grand mean"). In multiple regression analysis, the main effects are represented by the estimated parameter for the attribute and the grand mean is represented by the intercept term (Holmes and Adamowicz 2003). An interaction effect occurs if the response to the level of one attribute is affected by the level of another attribute. In a regression model, interaction effects are represented in the equation by the cross product of two (or more) variables. Interaction effects are important to economists because they identify the presence and strength of substitute and complementary relationships between/among attributes.

Fractional Factorial

The number of profiles necessary for a full factorial design can pose a significant burden on respondent patience and cognitive ability. Fractional designs reduce the number of profiles and reduce the burden on respondents. Typically, fractional designs also reduce the statistical efficiency of the experiment and may preclude identification of all substitutes and complements.

The construction of fractional factorial designs is a complex undertaking which is outside the scope of this introductory manual. Interested readers are directed to the example described in Holmes and Adamowicz (2003) for further information on this topic. A much more comprehensive treatment can be found in Johnson et al (2007).

Randomized

In a randomized design, each respondent is presented with a limited number of profiles drawn at random from a full profile. In principle, drawing a random sample from a full factorial design will result in an orthogonal design. Naturally, this result is premised on the statistics of large samples. Nonetheless, this approach avoids the considerable complexities associated with constructing a fractional factorial design.

In practice, random samples of arbitrary size can readily be constructed using commercially available software programs, spreadsheet software or custom programming efforts. Consequently, this technique has been employed in numerous conjoint analysis studies.

Survey Development

Like other examples of stated preference techniques, conjoint analyses are based on primary surveys. An impressive array of different survey approaches have evolved. Some of the more common approaches include mail surveys, in-person surveys, phone surveys, internet surveys and hybrid (mixed mode) combinations of all of these.

Perhaps the most important aspect of a survey is the clear, concise and efficient communication of the information pertinent to the attributes described. A large number of tools including maps, photos, text, graphics and drawings are often used to aid in this process. As with any survey, pre-testing of the instrument is essential to ensure the respondents understand the information being conveyed.

An excellent exposition of survey design for nonmarket valuation is contained in Champ (2003).

Elicitation Formats

Although there are many variants, three major types of survey elicitation formats are commonly encountered in surveys designed for conjoint analysis. These are ranking, rating, and choice based formats.

Early conjoint analyses relied on respondents to rank the profiles described in the survey instrument from most preferred to least preferred. Ranking of responses ostensibly provides the most information about a respondent's preferences. In addition to identifying the most preferred profile in the choice set, a ranking experiment provides information on preferences for all of the profiles in the choice set. From the statistical perspective, this additional information might lead to smaller standard errors for the estimated parameters or could require fewer observations for the same precision level. Practical experience has shown however that ranking is a more cognitively demanding task than making a single choice from a limited number of items in the choice set. Respondents can become confused or fatigued as they proceed through a ranking experiment. This can negate the apparent advantages of ranking as an elicitation format.

The second type of elicitation format is known as rating. For this approach, respondents are asked to express their preferences for a given profile using a numerical scale. This scale may have a range from 1 to 10 where 1 is "highly preferred" or most preferred and 10 is the "not at all preferred" or least preferred. Use of the rating approach allows one or more profiles to be identically scored, an outcome which is not possible when the ranking approach is employed.

It is assumed that respondent ratings reflect their underlying utility. Economic theory suggests ratings data represent an individual's ordinal rather than cardinal preferences. An ordinal interpretation only requires that a response of 3 on a rating scale represents a higher degree of preference than a 4 but does not necessarily represent the same cardinal degree of difference characterized by a rating of 2 relative to a rating of 3.

The econometric analysis of ratings data is relatively straightforward using ordered logit, ordered probit or even ordinary least squares. Relative to the analysis complexities inherent in the application of some other approaches, this is certainly appealing. In practice, some confounding issues can arise including the need to present a current or status quo condition as a baseline for analysis and the need to scale or adjust the ratings across individuals. These requirements along with the possibility of identical ratings for different profiles have resulted in recommendations by some authors to use alternative approaches.

A third approach is the choice-based elicitation format. Using this format, respondents are presented with one or more profiles and asked to select the profile which is most preferred. The theoretical foundation for choice-based conjoint experiments is the random utility maximization (RUM) model (see Appendix 1).

The choice-based elicitation format is said to mimic the actual market choices faced by consumers on a daily basis. This includes choices such as selecting a brand of cereal or deciding whether or not to purchase a good with particular levels of attributes from a set including similar goods with differing levels of attributes. This format is thought to focus a consumer’s attention on the tradeoffs between attributes that are necessary when making a decision.

Each of the three elicitation formats described above has advantages and disadvantages from the standpoint of the researcher. Clearly, selection of a particular format has implications both for the design of the survey and analysis of the resultant data. Consequently, the choice of elicitation format is a nontrivial decision for the analyst.

Collect Data

Once the survey design is complete, the next step is data collection or survey implementation. Recommended approaches for data collection are found in the classic treatise by Dillman (1978) and a more recent update (Dillman 2000). A rather comprehensive description of survey design, data collection and data management for stated and revealed preference surveys can be found in Champ (2003).

Estimate the Model

Using the data collected, a variety of econometric approaches are then used to estimate a conjoint model. The specific approach employed varies with the nature of the problem being addressed, the data collected, the response format (ranking, rating or choice), the skill of the researcher and other factors.

Interpret the Results

Finally, the estimated conjoint model is used for simulation purposes and to compute relevant economic welfare measures. These results are then interpreted for policy makers.

Economic Valuation Example

The example conjoint application which follows employs the dichotomous choice conjoint approach. It is based on the current public debate over the management of resources in Glen and Grand Canyons. This example is entirely hypothetical in nature and is designed to inform the reader about the potential application of conjoint analysis techniques to this policy relevant problem. The data employed in this example have been synthesized for this exercise.

Background and Setting

Glen Canyon Dam was completed by the U.S. Bureau of Reclamation in 1963. This 710 foot high concrete arch dam forms Lake Powell, which is 186 miles long and has an active storage capacity of 20.876 million acre feet (maf). There are eight hydroelectric generators at the dam, which can produce up to 1,320 megawatts (MW) of electric power (Seitz 2004).

The power produced at Glen Canyon Dam is sold by Western Area Power Administration (Western) to approximately 100 entities across a six-state area which includes Arizona, Colorado, New Mexico, Nevada, Utah, and Wyoming.

The construction of Glen Canyon Dam is closely associated with the rise of the modern environmental movement in the United States. The announcement of plans for and the eventual construction of the dam spurred a nationwide environmental protest (Martin 1991) which continues to this day (Brower 1997, Jacobs and Wescoat 2002). During the period from 1963 through 1991, Glen Canyon Dam was operated primarily to produce power during on-peak periods while meeting minimum flows during the remaining hours. These operations caused 7 to 12 foot daily fluctuations in the elevation of the river below the dam (Bureau of Reclamation 1994, Appendix D). These fluctuations have been shown to affect the quality of recreation (Bishop, et. al. 1987), aquatic and riparian resources (Gloss and Coggins 2005, Ralston 2005).

Several high profile environmental analyses have focused on the operation of Glen Canyon Dam. As detailed further in Appendix 4, the public debate over the operation of Glen Canyon Dam continues to this day and this site is the locus of ongoing litigation and additional environmental policy analysis.

The example application which follows borrows liberally from the terminology and alternatives examined in the Glen Canyon Long Term Experimental Plan (LTEP) EIS, described in Appendix 4. The LTEP-EIS focused primarily on the identification and analysis of experimental flow regimes which could improve the humpback chub population and enhance sediment retention, while minimizing the cost of doing so. Experiments described in the LTEP-EIS were envisioned to extend for a 10-20 year period.

Attributes

For purposes of constructing this conjoint exercise, we will focus on three Glen/Grand Canyon resources (attributes) which are arguably the most germane to the present Glen/Grand Canyon management dilemma. These attributes are; the program cost, the humpback chub population and the sediment resource.

Cost

The costs of the existing monitoring, research and management program in Glen and Grand Canyons are relatively extensive. The major components of this cost include the operation of the Glen Canyon Monitoring and Research Center (GCMRC), the costs of the Adaptive Management Program (AMP), related administrative costs including the costs of environmental compliance and the hydropower costs.

The bulk of these costs would change little, if any, with a change in flow regime. It should be recognized that only the incremental or marginal costs associated with an alternative are pertinent to the decision process.

The marginal costs of a change in release management regime include the incremental hydropower costs, if any, the construction costs related to the selected alternative, if any, and the additional operation and maintenance (O&M) costs, if any. Some of the alternatives considered in the LTEP-EIS process could include structural elements such as the installation of a temperature control device (for further information, see: www.du.edu/~dharpman/glenpage2.htm as well as Bureau of Reclamation 1999) and other mitigation measures, possibly even sediment augmentation measures (see Randle et al 2006). The costs of building these structures as well as their O&M costs are legitimately assigned to the alternative. Relative to the current condition, the hydropower costs of the alternatives will vary depending on whether the specified release regimes are more or less restrictive (see Harpman 1999, 2002).

The cost of implementing different alternatives may be less than, equal to, or greater than the costs incurred under the existing MLFF release management regime.

Ultimately, the costs associated with the management of Glen and Grand Canyons are borne by the American taxpayer (see explanation in Harpman and Douglas 2005). For purposes of this conjoint analysis exercise, we will define these costs in terms of dollars per American household over the life of the LTEP experimental treatment (10-20 years). More explicitly, the program cost is defined as the present value of the costs which might be incurred during that time-frame.

Humpback chub population index

The humpback chub, *Gila cypha,* in Glen and Grand Canyons is a federally listed endangered species. This long-lived desert species has been the subject of extensive research, rivaling in many cases, the research effort devoted to commercially exploited fish species. A description of the status of this and other Grand Canyon fish species is found in Gloss and Coggins (2005).

The population status of the humpback chub is the predominant factor shaping the choice of management regime at Glen Canyon Dam. Although there are many complications, for purposes of this conjoint analysis exercise, we will define a humpback chub population index. This index is normalized to the existing situation. For the current operational regime, the humpback chub index is defined to be 100%. Improvements in the population will result in a higher humpback chub population index (e.g. 150%) and declines in the population will yield lower values of the index (e.g. 40%). To reiterate an obvious point, this constructed index is defined relative to the current condition.

Sediment quantity index

The sediment resource is quite literally the foundation for the near-shore riparian and aquatic habitat. In addition, fine sediments, particularly sand, form the beaches upon which the recreational use of the Canyon depends. The amount of sediment entering Glen and Grand Canyons has been greatly diminished by the construction of Glen Canyon Dam. The physical morphology of the remaining sediment resource is affected by maximum releases and the operation of the dam. An informative description of the sediment resource and its current status can be found in Wright et al (2005).

The sediment resource is influenced by many interrelated factors. For purposes of this conjoint analysis exercise, we will construct a sediment index that embodies the quantity and physical morphology of this resource. By design, this index is normalized to the existing situation. For the current condition, the sediment index is defined to be 100%. Improvements in the condition of the sediment resource will result in a higher value of the sediment index (e.g. 120%) and declines in the condition of the resource, relative to the current condition, will yield lower values of the index (e.g. 60%).

Attribute Levels

Program cost.

For purposes of this exercise, six levels of the *incremental* program cost attribute were employed. These levels[1] were; $20.00, $40.00, $60.00 (no action

[1] The attribute levels described here were selected for purposes of this exercise. They may or may not reflect the range of attribute levels employed in an actual analysis.

condition), $80.00, $100.00 and $120.00 per household for the life of the experiment.

Humpback chub population.

Five levels of the humpback chub population index were employed in this conjoint experiment. For this attribute, the levels are defined as a percentage of the currently existing population of humpback chub population. The five levels of the humpback chub attribute used were 25%, 50%, 100% (no action condition), 200%, and 300%.

Sediment index.

Five levels of the sediment index were used in this conjoint experiment. Each level of this attribute is defined as a percentage relative to the existing sediment condition. The five levels of the sediment index attribute used in this experiment were: 40%, 80%, 100% (no action conditions), 120% and 160%.

The Relevant Population

Glen Canyon National Recreation Area and Grand Canyon National Park are both public resources. These national treasures were set aside to preserve their unique natural characteristics. They are nationally and internationally recognized. For these and other reasons, the identifiable stakeholder group affected by change in the status of these goods is the population of the United States.

Experimental Design

As described previously, there are three attributes, 6 levels of cost, 5 levels of the humpback chub index and 5 levels of the sediment index. A full-factorial experimental design is of size 6×5×5 or 150. The full-factorial design for this experimental specification is illustrated in Appendix 2. In this design, the levels of the attributes are orthogonal (linearly independent) of each other.

Clearly, no single respondent is likely to have the patience, cognitive stamina and concentration to rank, order, or choose between the 150 possible combinations of the three attributes and their respective levels.

In an actual application, some additional information could be obtained from focus groups, survey pretests and pilot tests. This information might allow for the construction of a statistically efficient fractional factorial design such as described in Johnson et al (2007). In this hypothetical case however, we have no such information. For this reason, and for reasons of simplicity, we assign three profiles to each survey by randomly sampling (with replacement) from the full-factorial design[2]. The large sample properties of this approach can be proven to preserve the orthogonal design.

Dichotomous Choice Conjoint

The simplest choice based conjoint approach, dichotomous or binary choice, is used in this example. This has a number of logistical and pedagogical advantages. Among these are:

- Illustrates similarities between conjoint analysis and contingent valuation.
- Allows the use of existing logit/probit econometric software.
- Consumer surplus measures are readily computed.

Survey Design

The central aspect of any conjoint survey is the nature of the scenarios presented to potential respondents. Figure 1 illustrates an example conjoint scenario. This scenario contains two profiles, each of which is based on the three Glen/Grand Canyon attributes and the levels described previously. Each scenario includes the no action or existing condition (Option "A") profile as a reference. The respondent makes his/her choice relative to the no action condition. The alternative (Option "B") is assigned randomly following the method described previously. For the scenario shown in Figure 1, the randomly assigned (alternative) profile has program cost level of $80.00, the level of the humpback chub index is 200% and the level of the sediment attribute is 80%. In the hypothetical application described, three randomly selected profiles are assigned to each survey.

For each of the three conjoint scenarios, a respondent would make a dichotomous choice by indicating whether they preferred option A or option B. Again, please note that option A in all of the profiles is the existing management regime and therefore all of the choices made by respondents are relative to this case.

[2] The procedure employed was slightly more complicated than described. Two additional rules were employed when assigning profiles to surveys. These rules were: (1) a profile was rejected if it was identical to the no action (existing) condition, and, (2) a profile was rejected if it had previously been assigned to the survey.

Effects	Option A (Existing condition)	Option B
Cost per household	$60.00	$80.00
Humpback chub Index	100%	200%
Sediment index	100%	80%
Choose A or B	**A** □	**B** ☒

Figure 1. Example Conjoint Scenario

What is Measured?

Although some individuals do use the river corridor in Glen and Grand Canyons, the vast majority of Americans do not. Previous studies have shown that members of the American public have strong preferences about the status of the natural resources potentially affected by the operation of Glen Canyon Dam (Welsh et al, 1995).

This hypothetical example describes a survey which would be administered to both users and nonusers of the resource. As such, it is constructed to measure total economic value. A further explanation of total economic value, use and nonuse value can be found in Appendix 3.

About the Data

For purposes of this exercise we will assume a well-designed survey was administered to members of the American public and 700 usable surveys were returned. Recall that each respondent was presented with three profiles like the one shown in Figure 1. For this reason, there are 2100=700×3 records in the resultant data set.

If the respondent indicated they preferred the alternative condition (option B in Figure 1), their response was coded as a "1," otherwise their response for this profile was coded as a "0."

The data for this exercise were generated synthetically using standard statistical methods. For those readers with an interest in this topic, the approach used to generate these data can be found in the Excel spreadsheet, *make_conj655datfile.xls*.

The data for the example analysis described in this manual may be found in the following files;

- *conj655.txt* (formatted for use by the MBMODEL program)
- *conj655.dat* (generic text file format without labels, headers)
- *make_conj655datfile.xls* (Excel format).

If these data were not supplied with this document, they may be obtained by contacting the author.

The descriptive statistics for the full n=2100 observation data set are shown in Table 2. The descriptive statistics shown in this table are employed in some of the calculations described subsequently.

Table 1. Descriptive Statistics for Example Data

	Resp	Cost	HBchub	Sedindx
mean	0.4986	70.3143	135.4524	99.8190
median	0.0000	80.0000	100.0000	100.0000
standard deviation	0.5001	33.9786	101.7195	40.2821
minimum	0.0000	20.0000	25.0000	40.0000
maximum	1.0000	120.0000	300.0000	160.0000

Parameter Estimation

In this example, the simplest possible estimation technique, dichotomous choice logit, is used to estimate the parameters for the conjoint function. Admittedly, a number of possible econometric nuances are ignored. In this case, each respondent is presented with three profiles and we might expect their three responses to be correlated. This suggests a more complex estimation procedure, such as the mixed logit approach (Train 2003) could be employed. Consistent with the educational purpose of this document, the simpler and more tractable dichotomous choice logit approach is used for parameter estimation.

A wide range of econometric software can be used for the analysis of the dichotomous choice conjoint example we have constructed. A subset of the software possibilities are LIMDEP (www.limdep.com), EViews (www.eviews.com), SHAZAM (http://shazam.econ.ubc.ca) and R (http://www.r-project.org). Using one of these software packages or a similarly capable program and the *conj655.txt* data set, a logistic regression equation can be estimated. The results shown in Box 1 were obtained using the MBmodel program[3]. The values of the estimated coefficients, obtained using another statistical package, should be very similar.

```
Multiple Bounded Regression Analysis              Ver 1.0.0  10/02/07

Logit model                                     run date = 1/23/2008
data file = MBconj655.dat                       run time = 9:30:26 AM

nobs =  2100            d.f. =  2096            nbids =  1
maxiter =  30           ctol = 1.0E-005         eps = 1.0E-005
iter =   4              converge = True

Study = SYNTHETIC CONJOINT DATA SET FROM FACTORIAL DESIGN 6*5*5

---------------------------------------------------------------------
variable        est coef        std err        t-stat      prob(t)
---------------------------------------------------------------------
const           1.597947        0.188676       8.4693    4.5747E-017
price        -4.4168E-002       0.001946     -22.6946    3.8846E-102
HBCHUB          0.005115     5.5684E-004       9.1858    9.5251E-020
SEDIND          0.008168        0.001379       5.9250    3.6409E-009
---------------------------------------------------------------------

log-likelihood = -1032.269675
Wald chi-square test ( 3 d.f) = 534.657702

E(WTP|WTP>=0) =      71.32
E(WTP) =      70.33


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```

Box 1. Logit Regression Results for the Example

As shown in Box 1, the estimated logit equation is highly significant (Wald Statistic 534.66). The coefficient for *cost* is -0.044168 and negative. The negative sign indicates that as the program cost increases, expressions of preference for an option decrease. This is consistent with economic theory and logic. The coefficients for *hbchub* and *sedindx* are positive. This indicates that individuals who consider the well-being of the humpback chub and sediment resources important, prefer options which improve the status of those resources, all other factors being held constant.

Each of the variables in the equation has a t-statistic greater than 3.00 and is significantly different from zero at greater than the 99% level. The median of the

[3] MBmodel is a multiple-bounded logit program developed by the author primarily for educational purposes. One advantage of this program is that it calculates the WTP measures described in Table 2.

WTP distribution is 70.33 and the conditional mean WTP is 71.32. There is only a small difference between the median (unconditional mean) and the conditional mean. This suggests that very little of the WTP distribution is located in the negative quadrant.

Estimated Logit Equation

The estimated coefficients shown in Text Box 1 can be substituted into the logit function to obtain the expression shown in equation (1).

(1) $$P = \frac{1}{1+e^{-bx}} = \frac{1}{1+e^{-(1.597947 - 0.044168\,price + 0.005115\,hbchub + 0.008168\,sedindx)}}$$

We will use this relationship for subsequent steps.

More Notation

A short digression about notation is useful in understanding the remaining sections of this document. In the logistic regression analysis context, the vector of explanatory variables multiplied by vector of coefficients (*bx*) may be expanded as shown in (2).

(2) $$bx = b_0 + b_1 x_1 + b_2 x_2 + \cdots + b_n x_n$$

In (2), b_0 is a constant term and $b_1 x_1$ through $b_n x_n$ are the other explanatory variables which typically include price, age, income and other variables.

In conjoint applications, one of these explanatory variables is the price posed to respondents. This is oftentimes referred to as the bid price or offer price. This is the price or cost associated with the potential change in management regime. Since P is often used to denote "Probability," the price or individual willingness to pay is often denoted as WTP.

As might be expected, economists are very interested in the coefficient on WTP (price). For reasons which will subsequently be made clear, they often collapse (2) into an expression consisting only of a so called "grand mean" denoted by alpha (α) and the price coefficient (*b*). This can prove confusing.

Assuming the price variable is x_1 and the price coefficient is b_1 , the grand mean is formed by summing the constant term (b_0) and all of the other terms, $b_2 x_2 \ldots b_n x_n$, evaluated at their means[4]. To reiterate, the grand mean includes the constant term and all of the explanatory variables except price. The resulting shorthand expression is shown in (3).

(3) $$bx = \alpha + b_1 x_1$$

In this widely used notation, α is the grand mean, *b* is the price coefficient and *x* is the price or WTP.

The expression shown on the right-hand side of (3) is used regularly in textbooks and articles. For consistency with these sources, the same notation is employed throughout the remainder of this document.

Graphing the Function

For purposes of visualization, it is useful to graph the estimated logit function with probability on the vertical axis and price on the horizontal axis. In order to plot this 4 dimensional expression (probability, *cost*, *hbchub*, *sedindx*), we must first reduce the number of dimensions to 2 (probability and price). The mean values for each of the variables in equation (1) are shown in Table 2. By convention, we reduce the dimensionality of the problem by multiplying the mean values for each of the variables, other than probability and price, by their coefficients and adding the result to the constant term. This process yields the grand mean (α) described previously.

To form the grand mean, we multiply the coefficients for *hbchub* and *sedindx* times their respective mean values and add this to the constant term. This calculation is shown in equation (4).

(4) $$\alpha = 1.597947 + 0.005115 \times 135.4524 + 0.008168 \times 99.8190$$

In this case, the grand mean or α=3.106108

Calculation of the grand mean allows us to reduce the problem to 2-dimensions—price and probability. In 2-dimensions, the multivariate logistic equation (1) becomes (5).

(5) $$P = \frac{1}{1 + e^{-(3.106108 - 0.044168\,price)}}$$

---

[4]Although the approach described here is used frequently in applied work, it is correctly applied only to linear functions. In the case of nonlinear functions, such as the logit function, Souter and Bowker (1996) have shown it can yield biased estimates of aggregate consumer surplus.

Equation (5) can then be plotted in two dimensions (price and probability) as shown in Figure 2. As shown in this figure, a small portion of the estimated distribution is located in the negative quadrant (not shown).

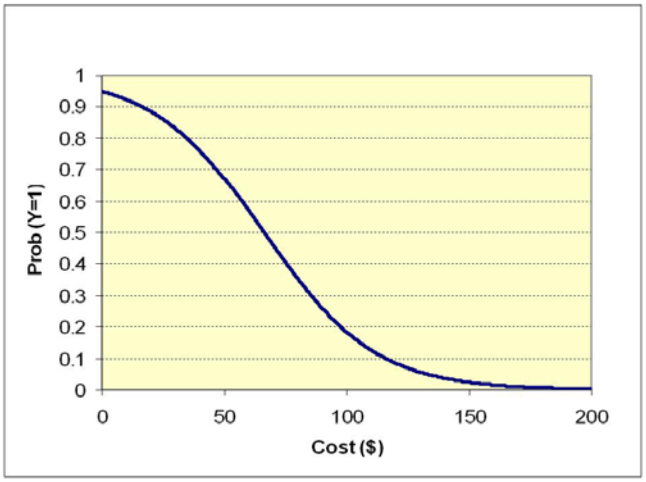

Figure 2. Plot of estimated probability function

Consumer Surplus (CS) Measures

The estimated logit function is a cumulative probability density function. This function describes the (cumulative) probability that an individual will prefer the alternative profile at various bid or price levels. The mean or expected value of the consumer surplus is usually written as E(WTP). The E(WTP) is the area under the logit function. This area is often reported as the "consumer surplus."

In general, the expected value of an arbitrary cumulative probability density function is computed over the domain from $-\infty$ to $+\infty$. Consumer willingness to pay (WTP) is typically defined as a non-negative measure. The domain of the logit function is not necessarily non-negative and, in many applications, some portion of the estimated function lies in the negative quadrant. For purposes of computing the expected value of consumer surplus, most economists use the domain from 0.0 to $+\infty$. Integrating over this domain yields what is correctly called the conditional mean[5] which is often denoted as $E(WTP|WTP \geq 0)$. Table 3 illustrates expressions for the mean, median and conditional mean willingness to pay for the *linear* in parameters logit function.

---

[5] Conditional on the presumption $WTP \geq 0$.

In the expressions in Table 3, α is the "grand mean" for the estimated logistic regression and *b* is estimated coefficient for the price variable. As shown in this table, the expressions for the median consumer surplus and the mean consumer surplus are identical for the linear in parameters logit model.

Table 2. Measures of Consumer Surplus

Measure	Integration Interval	Notation	Expression[6]
Median	-∞ to +∞	Prob(WTP)=0.50	$\frac{-\alpha}{b}$
Mean	-∞ to +∞	E(WTP)	$\frac{-\alpha}{b}$
Conditional Mean	0.0 to +∞	E(WTP|WTP≥0)	$\frac{\ln(1+e^{\alpha})}{-b}$

The median consumer surplus is the willingness to pay that corresponds to a probability of 0.50. Simple algebra can be used to derive the expression for the median. Hanemann (1989) derived the expression for the conditional mean consumer surplus using the method of moments. Appendix 5 illustrates the derivation of this expression using standard calculus techniques.

The consumer surplus measures for the linear in parameters logit model, other specifications of the logit model and many other forms of dichotomous choice models (e.g. log-normal, weibull, etc.) can be found in Hanemann and Kanninen (1999).

For the majority of economists, consumer surplus is a non-negative quantity. Consequently, the conditional mean consumer surplus is by far the most widely reported measure of willingness to pay. Using the expression for conditional consumer surplus shown in Table 3, the previously calculated grand mean (α) and the price coefficient (*b*), the conditional willingness to pay is calculated as shown in (6).

[6] To reiterate, these measures are valid only for the linear in parameters logit function.

(6) $$E(WTP \mid WTP \geq 0) = \frac{\ln(1+e^{3.106108})}{0.044168} = \$71.32$$

Evaluation of this expression yields a WTP of $71.32. This consumer surplus measure is computed by the MBMODEL model and is reported in the results shown in Box 1.

The graphical equivalent of the conditional mean consumer surplus is illustrated in Figure 3.

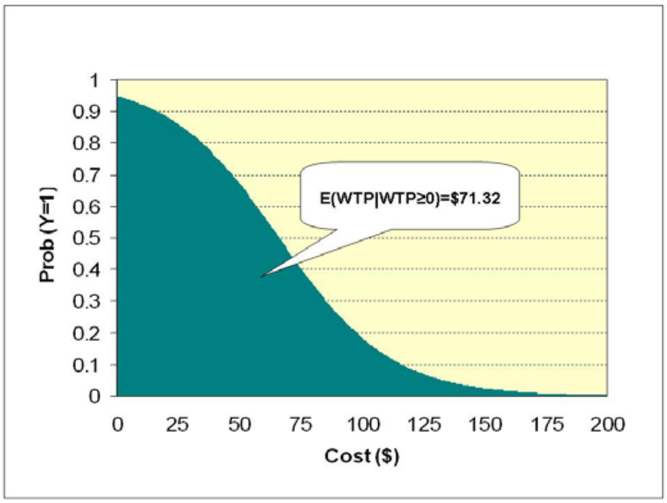

Figure 3. Conditional consumer surplus

The median or unconditional mean consumer surplus is also reported in many studies. The median represents the expected value of the WTP distribution over the interval -∞ to +∞. Using the grand mean (α) and the price coefficient (*b*), calculation of the (unconditional) mean and median consumer surplus is shown in equation (7).

(7). $$Median\_WTP = \frac{-(3.106108)}{-0.044168} = \$70.33$$

Confidence Intervals

Confidence intervals for any one of the consumer surplus measures can be estimated using one of several numerical techniques. A fuller discussion of these methodologies is beyond the scope of this introductory document. Box 2 displays the 90%, 95% and 99% empirical confidence intervals for the conditional mean consumer surplus computed using the Krinsky and Robb (1986) technique. The

KR_MBL program used to estimate these confidence intervals was developed by the author based on code graciously provided by Park, Loomis and Creel (1991).

```
Multiple Bounded Regression Analysis        Ver 1.0.0  10/02/07

Logit model                                 run date = 1/23/2008
data file = MBconj655.dat                   run time = 9:30:26 AM


ESTIMATION OF KRINSKI & ROBB CONFIDENCE INTERVALS

cs formula used = Logit E(WTP|WTP>=0)
number of trials = 1000


Study = SYNTHETIC CONJOINT DATA SET FROM FACTORIAL DESIGN 6*5*5


                           CONSUMER SURPLUS

                  ==================================

                  CI            Trimmed        CI
                  Lower           Mean         Upper
                  ----------------------------------

      99% C.I.     68.29         71.30         74.67

      95% C.I.     69.04         71.29         73.85

      90% C.I.     69.34         71.29         73.25


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```

Box 2. Confidence Intervals for Conditional Mean Consumer Surplus

As shown in Box 2, the 99% empirical confidence intervals for the conditional mean consumer surplus ranges from $68.00 to $74.01. We conclude the true value of mean consumer surplus falls within this interval 99% of the time. Alternatively, we can say we are 99% confident the true value of mean consumer surplus falls within this interval.

Example Policy Analysis

There are many possible flow experiments at Glen Canyon Dam which might be considered by policy-makers. It may be useful to choose one specific example and compare its benefits to those of the no action or base case operations. For instance, suppose an alternative which improves the population status of the humpback chub is being considered. Let's call this Alternative X. Assume Alternative X improves the population index from 100% to 200%. We will further assume Alternative X has no effect on the level of the sediment attribute and its value remains at 100% (same as the no action case).

Without elaboration, we will presume that the additional cost of this improvement is $10.00 more per American household over the life of the experiment. If we assume there are 100 million households in the United States, this implies the total cost of Alternative X is approximately $1,000,000,000. This hypothetical increase in cost could be composed of the following: (a) increases in the costs of the monitoring, research and management program in Glen and Grand Canyons, (b) the costs of changes in hydropower operations, and (c) potentially, the construction costs associated with implementing the alternative.

Our task is to estimate the benefits stemming from this improvement. The goal is to compare the estimated benefits to the cost of the program.

No Action Consumer Surplus

As described earlier, the levels of the humpback chub and sediment attributes have been constructed such that their levels are equal to 100% for the no action or base case.

Following the procedures we have detailed previously in this document, the first step in estimating the consumer surplus for the no action case is to calculate the grand mean (α) for this specific case.

To form the grand mean, we multiply the coefficients for *hbchub* and *sedindx* times their base case values and add this to the constant term. This calculation is shown in equation (8).

(8) $$\alpha = 1.597947 + 0.005115 \times 100.00 + 0.008168 \times 100.00$$

For the no action alternative, the grand mean or α=2.926247.

We can use the expression shown in Table 3 to calculate the unconditional mean consumer surplus (also known as the median) which is reported in some economic studies. Using the grand mean (α) we have calculated in equation (8) and the value of the price coefficient (*b*), calculation of the (unconditional) mean or median consumer surplus is shown in equation (9).

(9). $$Median\_WTP = \frac{-(2.926247)}{-0.044168} = \$66.25$$

Evaluation of this expression yields a consumer surplus value of $66.25. This value represents the (unconditional) mean net economic value of the existing or no action operations at Glen Canyon Dam to an average household over the life of the experiment.

Next, we can calculate the more commonly encountered conditional mean consumer surplus measure. Using the expression for conditional consumer surplus shown in Table 3, the grand mean (α) we have just calculated (8) and the value of the price coefficient (*b*), we calculate the conditional willingness to pay as shown in (10).

$$(10) \qquad E(WTP \mid WTP \geq 0) = \frac{\ln(1+e^{2.926247})}{0.044168} = \$67.43$$

Evaluation of this expression yields a WTP of $67.43. This value is interpreted as the (conditional) mean net economic value of the existing management regime at Glen Canyon Dam to an average American household over the life of the experiment.

Alternative X Consumer Surplus

For Alternative X, the level of the humpback chub attribute has been improved from 100 (base case) to 200. For this hypothetical alternative, the level of the sediment attribute remains unchanged at 100.

Following the same process we used previously, the first step in estimating the consumer surplus for Alternative X is to calculate the grand mean (α) for this case.

To form the grand mean, we multiply the coefficients for *hbchub* and *sedindx* times their values in this alternative and add the results to the constant term. This calculation is shown in equation (11).

$$(11) \qquad \alpha = 1.597947 + 0.005115 \times 200.00 + 0.008168 \times 100.00$$

For Alternative X, the grand mean or α=3.437747.

We can use the expression shown in Table 3 to calculate the unconditional mean consumer surplus (or median) which is reported in some economic studies. Using the grand mean (α) we have calculated for Alternative X and the value of the price coefficient (*b*), calculation of the (unconditional) mean or median consumer surplus is shown in equation (12).

$$(12). \qquad Median\_WTP = \frac{-(3.437747)}{-0.044168} = \$77.83$$

Evaluation of this expression yields a surplus value of $77.83. This value represents the (unconditional) net economic value of Alternative X operations at Glen Canyon Dam to an average American household over the life of the experiment.

Using the expression for conditional consumer surplus shown in Table 3, the grand mean (α) we have just calculated for Alternative X (11) and the value of the price coefficient (*b*), we can also calculate the conditional willingness to pay as shown in (13).

(13) $$E(WTP \mid WTP \geq 0) = \frac{\ln(1+e^{3.437747})}{0.044168} = \$78.55$$

Evaluation of this expression yields a WTP of $78.55. This value represents the (conditional) net economic value of Alternative X operations at Glen Canyon Dam to an average American household over the life of the experiment.

Incremental Benefits

The incremental net benefit of the improvement in the humpback chub population index associated with Alternative X is the difference in value between the no action case and the alternative. Conceptually, this is the difference between the areas under the two logistic regression functions as shown in Figure 4.

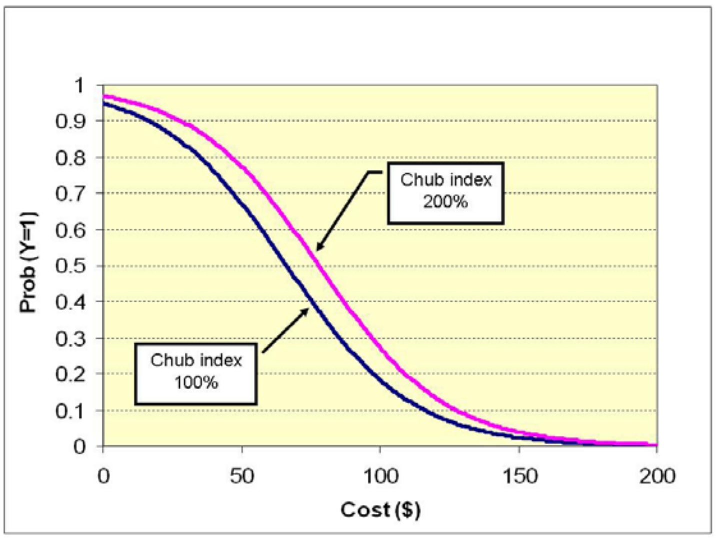

Figure 4. The benefit of increasing the chub population index is the difference between the areas under the two curves

If the quantitative measure of interest is the unconditional mean consumer surplus, the incremental difference in net economic benefits is $11.58=77.83-66.25 per American household over the life of the experiment. If our focus is on the conditional mean consumer surplus, the difference in net economic benefits is $11.12=78.55-67.43 per American household over the life of the experiment. As shown in Table 3, if we assume there are 100 million households in the United States, the aggregate net benefits of implementing Alternative X, are $1,158,000,000 and $1,112,000,000 respectively.

Interpretation of Results

We assumed earlier the cost of Alternative X was $10.00 per American household over the life of the experiment. Since the estimated benefit of this improvement is $11.12 and $11.58 for the conditional mean and unconditional mean respectively per household, the benefits of the proposed Alternative X exceed the cost. We may conclude the investment in this proposed program is economically efficient.

Table 3. Benefits of Alternative X

Consumer Surplus Measure	Household Benefits[7] ($)	Aggregate[8] Benefits ($)
E(WTP|WTP≥0)	11.12	1,112,000,000
E(WTP)	11.58	1,158,000,000

Advantages of CA

Holmes and Adamowicz (2003) describe the advantages of conjoint analysis as follows:

- The experimental stimuli are under the control of the researcher as opposed to the lack of control generally afforded by observing the real market place. This includes the introduction of new attributes and attributes associated with passive use values that cannot be observed in the market.
- The use of statistical design theory yields greater statistical efficiency and eliminates collinearity between explanatory variables.
- A multi-dimensional response surface is modeled that provides a richer description of preferences than can be obtained by the valuation of single “with versus without” scenarios. This richness enhances the application of ABMs to managerial decision making.
- Salient attributes of the valuation problem are clearly circumscribed. Attributes are traded off in the process of value elicitation so the reductions in one attribute may be compensated by an increase in another attribute.

[7] Present value of benefits over the life of the experiment.
[8] Assuming there are 100 million households in the United States.

Disadvantages of CA

As described, conjoint analysis appears to have a number of advantageous features. In addition, it has some disadvantages. Among these disadvantages are the following:

- Although the conjoint method has been a feature of the recent literature, it remains a relatively new approach.
- Conjoint analysis is a survey based stated preference technique. As such, it is subject to many of the same application challenges as contingent valuation.
- Conjoint analysis may place a greater burden on respondents. Typically, a conjoint survey contains a number of scenarios and/or pair-wise trade-offs which must be considered by the respondent. Respondents may become bored or fatigued in the process. As a result, responses to questions later in the sequence may be of lower quality.
- Similar to contingent valuation surveys, respondents to conjoint surveys may be unfamiliar with the nature of trade-offs between amenities and can be cognitively challenged.
- Like contingent valuation surveys, respondents may be unfamiliar with the different attributes and levels of the amenities described in the survey.

Conclusions

The goal of this document is to introduce the conjoint method, its statistical underpinnings and the mechanics of its application. The historical background, typical approaches and the steps required to undertake a conjoint study are described. The nature of the relevant consumer surplus measures are explained, their mathematical expressions reported and the derivation of these measures is illustrated. Finally, a step-by-step application of the DC conjoint method is presented. This example application is designed to allow readers to understand and apply the methodology. The solved hypothetical example is based on an on-going policy dilemma at Glen Canyon Dam. Although the progress of economic science continues, the conjoint method is currently regarded as the “state-of-the-art” in nonmarket valuation. Many future applications of this rapidly evolving methodology are expected. It is hoped this manual will provide economists, environmental scientists and policy makers some conceptual and technical insight into this evolving valuation technique.

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Appendix 1. The RUM Model

Much of the recent research employing conjoint analysis for the valuation of environmental amenities is based upon the random utility maximization (RUM) model. In the RUM model, utility (U) is assumed to be the sum of a systematic component (v) and a random component (ε) as shown in equation (14).

(14) $$U_j = v(x_j, p_j; B) + \varepsilon$$

In equation (14), U_j is the true but unobservable indirect utility associated with profile *j*, x_j is a vector of attributes associated with profile *j*, p is the cost of profile *j*, *B* is a vector of parameters, and ε_j is a random error term with mean zero. An individual's choice behavior is assumed to be deterministic (without error) from the perspective of the consumer, but stochastic from the viewpoint of the researcher. Because the researcher is unable to observe everything about the consumer, the error term in the random utility expression reflects researcher uncertainty about an individual's choice.

It is typically assumed that utility is separable and linear in the parameters. This yields expression (15).

(15) $$U_j = \sum_{k=1}^{L} B_k x_{jk} + B_p p_j + \varepsilon_j$$

In expression (15), B_k is a vector of preference parameters associated with attribute *k*, x_{jk} is attribute *k* in profile *j*, and B_p is the parameter on profile cost.

To reiterate, expression (15) is an additively separable linear in parameters utility expression. By differentiating expression (15) with respect to x_k, it can be readily shown that the parameter estimates (*B*'s) are marginal utilities. For example, $\partial U/\partial x_1 = B_1$. The estimated parameter for price (B_p) has a special interpretation. Because an increase in the profile price reduces income, B_p measures the change in utility associated with a marginal decrease in income. For this reason, the negative of the estimated profile price parameter is interpreted as the marginal utility of income.

When the interactions between attributes are considered in the experimental design, a utility functions that includes these interactions can be specified as shown in (16).

(16)
$$U_j = \sum_{k=1}^{L} B_k x_{jk} + B_p p_j + \sum_{m=1}^{m=L} \sum_{k=1}^{k=L} B_{km} x_{jk} x_{jm} + \varepsilon_j$$

In this equation, B_{km} is a vector of preference parameters for interactions between attributes *k* and *m* in profile *j*, and x_{jk} and x_{jm} are attributes *k* and *m* in profile *j*. This expression includes all possible substitution and complementarity relationships between the attributes.

Appendix 2. Full-Factorial Design

cell	cost	hbchub	sedindx
1	20.00	25	40
2	20.00	25	80
3	20.00	25	100
4	20.00	25	120
5	20.00	25	160
6	20.00	50	40
7	20.00	50	80
8	20.00	50	100
9	20.00	50	120
10	20.00	50	160
11	20.00	100	40
12	20.00	100	80
13	20.00	100	100
14	20.00	100	120
15	20.00	100	160
16	20.00	200	40
17	20.00	200	80
18	20.00	200	100
19	20.00	200	120
20	20.00	200	160
21	20.00	300	40
22	20.00	300	80
23	20.00	300	100
24	20.00	300	120
25	20.00	300	160
26	40.00	25	40
27	40.00	25	80
28	40.00	25	100
29	40.00	25	120
30	40.00	25	160
31	40.00	50	40
32	40.00	50	80
33	40.00	50	100
34	40.00	50	120
35	40.00	50	160
36	40.00	100	40
37	40.00	100	80
38	40.00	100	100
39	40.00	100	120
40	40.00	100	160
41	40.00	200	40
42	40.00	200	80
43	40.00	200	100
44	40.00	200	120
45	40.00	200	160
46	40.00	300	40
47	40.00	300	80
48	40.00	300	100
49	40.00	300	120

50	40.00	300	160
51	60.00	25	40
52	60.00	25	80
53	60.00	25	100
54	60.00	25	120
55	60.00	25	160
56	60.00	50	40
57	60.00	50	80
58	60.00	50	100
59	60.00	50	120
60	60.00	50	160
61	60.00	100	40
62	60.00	100	80
63	60.00	100	100
64	60.00	100	120
65	60.00	100	160
66	60.00	200	40
67	60.00	200	80
68	60.00	200	100
69	60.00	200	120
70	60.00	200	160
71	60.00	300	40
72	60.00	300	80
73	60.00	300	100
74	60.00	300	120
75	60.00	300	160
76	80.00	25	40
77	80.00	25	80
78	80.00	25	100
79	80.00	25	120
80	80.00	25	160
81	80.00	50	40
82	80.00	50	80
83	80.00	50	100
84	80.00	50	120
85	80.00	50	160
86	80.00	100	40
87	80.00	100	80
88	80.00	100	100
89	80.00	100	120
90	80.00	100	160
91	80.00	200	40
92	80.00	200	80
93	80.00	200	100
94	80.00	200	120
95	80.00	200	160
96	80.00	300	40
97	80.00	300	80
98	80.00	300	100
99	80.00	300	120
100	80.00	300	160
101	100.00	25	40
102	100.00	25	80
103	100.00	25	100
104	100.00	25	120
105	100.00	25	160
106	100.00	50	40

107	100.00	50	80
108	100.00	50	100
109	100.00	50	120
110	100.00	50	160
111	100.00	100	40
112	100.00	100	80
113	100.00	100	100
114	100.00	100	120
115	100.00	100	160
116	100.00	200	40
117	100.00	200	80
118	100.00	200	100
119	100.00	200	120
120	100.00	200	160
121	100.00	300	40
122	100.00	300	80
123	100.00	300	100
124	100.00	300	120
125	100.00	300	160
126	120.00	25	40
127	120.00	25	80
128	120.00	25	100
129	120.00	25	120
130	120.00	25	160
131	120.00	50	40
132	120.00	50	80
133	120.00	50	100
134	120.00	50	120
135	120.00	50	160
136	120.00	100	40
137	120.00	100	80
138	120.00	100	100
139	120.00	100	120
140	120.00	100	160
141	120.00	200	40
142	120.00	200	80
143	120.00	200	100
144	120.00	200	120
145	120.00	200	160
146	120.00	300	40
147	120.00	300	80
148	120.00	300	100
149	120.00	300	120
150	120.00	300	160

Appendix 3. Total Economic Value

Description

Social scientists have long acknowledged the possibility that humans could be affected by changes in the status of features of the natural environment even if they never visit or otherwise use these resources. These individuals may be classified as non-users, and economic expressions of their preferences regarding the status of the natural environment are termed "nonuse" or "passive use" value.

Total economic value (TEV) is composed of use and nonuse value. In many instances, at least some proportion of the population use the resource and are also affected by changes in its status. These individuals have both use and nonuse value for the resource. Research has shown there is no acceptable methodology for separating nonuse economic value from use value. As a consequence, members of the economics profession typically employ the term, "total economic value."

Aquatic and riparian resources along the Colorado River are directly affected by the operations of Glen Canyon Dam. Although visitation to Glen Canyon National Recreation Area and the Grand Canyon National Park is quite extensive, reaching 6.2 million visitors in 2006 (NPS 2007), only a very small proportion of these visitors physically use these riverine resources. Nonetheless, visitors to the Grand Canyon and members of the general public hold strong preferences about the status of these resources. Collectively, this is properly referred to as total economic value.

The literature on nonuse value emphasizes the uniqueness of the resource in question and the irreversibility of the loss or injury. Frequently mentioned factors that might give rise to nonuse value include:

- Desire to preserve the functioning of specific ecosystems.
- Feeling of environmental responsibility or altruism toward plants and animals.
- Preservation of iconic examples of nature and natural features.

TEV and Glen Canyon Dam

The Glen and Grand Canyon resources are known throughout the Nation and the world. In 1975, the Grand Canyon was declared by the Congress to be "a natural feature of national and international significance" (Pubic Law 93-620, 16 U.S.C. 228a). It was designated as a World Heritage Site in 1979. The Colorado River in the Grand Canyon has been designated as critical habitat for two species of endangered native fish (see Gloss and Coggins 2005). The Grand Canyon is, in fact, often cited as an example of a resource for which nonuse value is significant. The National Academy of Science Committee to Review the Glen Canyon recognized this significance and noted that the Glen Canyon Environmental Studies Phase I economic studies failed to consider nonuse value (National Research Council 1987).

As related in Harpman (1995), the Bureau of Reclamation retained an independent consulting company to complete an analysis of total economic value for the Glen Canyon EIS. Welsh et al (1995) undertook a comprehensive study of total economic value for Glen and Grand Canyon resources. Their research encompassed both individuals residing within the area where electricity from the dam is sold and all citizens of the United States. The survey instrument was painstakingly designed following a series of focus groups, a peer review and an extensive pilot-test. Survey response rates were exceptional; 83% and 74% for the power marketing area and national samples respectively. In many respects, these response rates demonstrated the saliency of these resources to stakeholders and members of the public.

Welsh et al (1995) estimated the average willingness to pay by households in the marketing area for moderate(d) fluctuations was $27.94 per year and the average willingness to pay by households across the U.S. was $17.06 per year. When expanded by the pertinent populations, this yields aggregate estimates of $79 million per year for the marketing area and $2,858 million for the national sample. The findings of this study clearly illustrate the significance of Grand Canyon resources and the value placed upon them by members of the public.

Appendix 4. Additional Background

The 1996 Glen Canyon Dam EIS

The Operation of Glen Canyon Dam Environmental Impact Statement (GCDEIS) was initiated in 1989 to examine options which, "... minimize-- consistent with law-- adverse impacts on downstream environmental and cultural resources and Native American interests...". The environmental impacts of nine operational alternatives, ranging from unrestricted hydropower operations to baseloading of the powerplant, were examined in the final GCDEIS (Bureau of Reclamation 1995).

On October 9, 1996, Secretary of the Interior, Bruce Babbit, issued a record of decision (ROD) on future operations of Glen Canyon Dam. Based largely on Endangered Species Act considerations, the Secretary announced that the facility will be operated according to the Modified Low Fluctuating Flow (MLFF) alternative. Under MLFF there are new restrictions on maximum flows, minimum flows, ramp rates, and the daily change in flow. Table 1 compares historical and MLFF operating criteria.

Table 4. Historical and MLFF Operating Criterion

	Historical Operation Criteria	Modified Low Fluctuating Flow[a]
Minimum releases (cfs)	1,000 Labor Day-Easter 3,000 Easter-Labor Day	8,000 between 7 a.m. and 7 p.m. 5,000 at night
[b] Maximum releases (cfs)	31,500	[c] 25,000
Allowable daily flow fluctuations (cfs/24 hours)	Unrestricted	[d] 5,000 6,000 or 8,000
Up-Ramp Rates (cfs/hour)	Unrestricted	4,000
Down-Ramp Rates (cfs/hour)	Unrestricted	1,500

[a] Non-operational elements and periodic special releases such as beach-building and habitat-maintenance flows are not included in this table. See Bureau of Reclamation (1995) for details.
[b] Maximums may necessarily be exceeded during high water release years.
[c] Will be exceeded during beach-building and habitat-maintenance flows.
[d] Daily fluctuations are limited to 5,000 cfs for monthly release volumes less than 600,000 acre-feet; 6,000 cfs for monthly release volumes of 600,000 to 800,000 acre-feet; and 8,000 cfs for monthly volumes over 800,000 acre-feet.

The MLFF operating criteria shown in Table 1 were designed to reduce fluctuations in river elevation to a range of from 1 to 3 feet (Bureau of Reclamation 1994, Appendix D). Minimum flows, maximum flows, ramp rates, and allowable daily fluctuations were established with the goal of protecting downstream resources while allowing limited flexibility for power operations. A key component of MLFF is adaptive management. Adaptive management is a process, "...whereby the effects of dam operations on downstream resources would be assessed and the results of those resource assessments would form the basis for future modifications of dam operations (Bureau of Reclamation 1995 p. 34)".

The LTEP EIS

In November 2005, the Center for Biological Diversity (www.biologicaldiversity.org) and Living Rivers (www.livingrivers.org) jointly filed a 60 day notice of intent (NOI) to file a lawsuit against the U.S. Fish and Wildlife Service and the U.S. Bureau of Reclamation. These entities contended that in violation of the Endangered Species Act, the Adaptive Management Program has failed to protect endangered species. As evidence, they cited several findings described in, *The State of the Colorado River Ecosystem in Grand Canyon* (SCORE) report (for example, see Gloss and Coggins 2005, Ralston 2005). Following discussions between the parties, a settlement agreement was reached in August 2006. One component of this agreement was the initiation of the Long Term Experimental Plan (LTEP) Environmental Impact Study.

The Glen Canyon Long Term Experimental Plan (LTEP) EIS process was initiated in December 2006. As stated in the NOI, the purpose and need for the forthcoming EIS is:*"The purpose of the proposed action is to increase scientific understanding of the ecosystem downstream from Glen Canyon Dam and to improve and protect important downstream resources. Specific hypotheses to be addressed include the effect of dam release temperatures; ramp rates; non-native control; and the timing, duration, and magnitude of beach/habitat-building flow (BHBF) releases. Adoption of a Long-Term Experimental Plan is needed to ensure a continued, structured application of adaptive management in such a manner as to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established, including, but not limited to natural and cultural resources and visitor use, consistent with applicable Federal law."* (Bureau of Reclamation 2006).

The focus of the LTEP-EIS was primarily to identify alternatives which will improve the humpback chub population and enhance sediment retention while minimizing the cost of doing so. The LTEP was envisioned to extend for a 10-20 year period.

More Recent Events

After the LTEP Environmental Impact Study was begun, there were further legal events. In September 2007, the Grand Canyon Trust (www.grandcanyontrust.org) filed a 60 day NOI to file suit against U.S. Fish and Wildlife Service and the U.S. Bureau of Reclamation. The Grand Canyon Trust asserted there are current and continuing procedural and substantive violations of the Endangered Species Act, specific to the 1994 Biological Opinion on the Operation of Glen Canyon Dam. In November 2007, a litigation hold was placed on the LTEP-EIS process. At the present time, the Department of the Interior's legal council is assessing the situation.

Appendix 5. Conditional Mean WTP

This appendix illustrates how to derive the expression for the conditional mean consumer surplus, E(WTP|WTP≥0), using standard calculus techniques.

The logistic or logit function is described by (17) where *x* is a matrix and *b* is a conformable vector of constant coefficients.

(17) $$F(x)=\frac{1}{1+e^{-bx}}$$

This function is a cumulative probability function. In various guises, it is used both in population models and logistic regression analysis. In both situations, it sometimes may be desirable to identify a closed form (analytic) solution for the expected value (E(x)) over an integration range of 0 to -∞. This is typically described as the conditional expected value of x and is written in mathematical short-hand as E(x|x≥0). Equation (18) illustrates this expression.

(18) $$\int_0^\infty F(x)dx=\int_0^\infty \frac{1}{1+e^{-bx}}dx$$

In frequently cited paper, Hanemann (1989) reported the closed form solution for this problem which he obtained using the method of moments. This result can also be obtained with standard calculus.

First, recall that for any constant, k, equation (19) holds.

(19) $$\int kF(x)dx=k\int F(x)dx$$

Then note the logit function can be expressed in a number of equivalent forms. Of particular interest to us is (20).

(20) $$\frac{1}{1+e^{bx}}=\frac{e^{bx}}{e^{bx}+1}$$

If we integrate the form shown on the right-hand side of (20) our task will be made much easier. To do so, first define *k=b/b*. Then using (19) and (20) we obtain equation (21).

(21) $$\int_0^\infty \mathrm{F(x)\,dx}=\int_0^\infty \frac{b}{b}\frac{e^{bx}}{e^{bx}+1}dx=\frac{1}{b}\int_0^\infty \frac{be^{bx}}{e^{bx}+1}dx$$

Next, we can apply the standard rule for integrating 1/u so that we end up with expression (22).

$$\int_0^{\infty} F(x)dx = \frac{1}{b} Ln(e^{bx} + 1) + c \qquad (22)$$

In (22) *c* is a constant of integration. Expression (22) is identical to the relationship derived by Hanemann (1989).