Western Regional

Research Project W-133

Benefits and Costs in Natural Resources Planning

Third Interim Report

Edited by

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October 5, 1990

BENEFITS AND COSTS IN NATURAL RESOURCES PLANNING

THIRD INTERIM REPORT

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Preface

This document reports research findings presented at the February, 1990, meeting of Western Regional Project W-113. The meeting was held cooperatively with the Western Regional Science Association at the Kaluakoi Hotel on Molokai, Hawaii, from February 20 to 23. Appendix A lists the agenda for the February meeting.

The purpose of W-133 is to encourage regional interaction and research involving the use of benefit and cost information in natural resources planning. The specific objectives of W-133 are:

1. To conceptually integrate market and nonmarket based valuation methods for application to land and water resource base services.

2. To develop theoretically correct methodology for considering resource quality in economic models and for assessing the marginal value of competing resource base products.

3. To apply market and nonmarket based valuation methods to specific resource base outputs.

The 22 papers presented at the February meeting demonstrate that significant progress has been made toward these objectives.

The purpose of this volume is to record and communicate the results presented at the February meeting. All presenters at the meeting were encouraged to submit a working paper to this volume. Fifteen papers were received for publication in this volume.

In reading this document, the reader should keep in mind that the papers are working drafts and the reported results are preliminary. The reported results are tentative and may change with further analysis. The authors have approved the use of their working drafts for this publication in the interests of furthering scholarly communication and interaction. Those interested in final research results should contact the authors at their listed research institutions.

John P. Hoehn
East Lansing, Michigan
October 5, 1990

APPENDIX A

W-133 ANNUAL MEETING AGENDA

APPENDIX A

W-133 Annual Meeting Agenda
Kaluakoi Hotel, Molokai, Hawaii
February 20-23, 1990

The general plan of the meeting is as follows. We will have a reception for all W-133 members and friends on the evening of Tuesday, February 20, in the Kaluakoi Hotel from 7:00-9:00 pm. The first day of the meeting, February 21, will be our accustomed workshop session. We will start and end the Wednesday session earlier than usual given the time change in Hawaii. The second day of the meeting will be our joint sessions with the Western Regional Science Association. We will conclude on the morning of February 23 with a morning business meeting. If the group prefers, we can move the business meeting to the evening of February 21.

Tuesday, February 20

7:00- 9:00 pm -- ***Reception for All Members and Friends, Kaluakoi Hotel***

Wednesday, February 21

7:30- 7:45 am -- ***Welcome, Opening Remarks, and Organization Notes***
John Hoehn

7:45- 9:45 am -- ***Issues in Contingent Valuation***
Kevin Boyle, Moderator

John Bergstrom, University of Georgia, "*Recreational Benefits of Reservoir High-Water Levels*"

John Duffield, University of Montana, "*Quality and Quantity Effects on In-Stream Flow Values*"

Olvar Bergland, Gregory Perry, Oregon State University and Rulon Pope, Brigham Young University, "*Old Growth Forest Valuation: A Comparison of Survey Designs*"

Teo Ozuna and John Stoll, Texas A&M University, *Confidence Intervals for Truncated Logistic Valuation*"

9:45-10:00 am -- ***Break***

10:00-12:00 pm -- ***Resource Valuation in a Policy Context***
Kevin Boyle, Moderator

Linda Langner, U.S. Forest Service, "*RPA Values for Forest Service Program Evaluation*"

Richard Aiken, U.S. Fish and Wildlife Service, *"1991 National Survey of Fishing, Hunting and Wildlife Associated Recreation,"* and *"Survey Respondent Recall Study"*

James Miller, National Program Leader Fish and Wildlife, Extension Service, USDA, *"Recreational Access to Private Land: Problems, Opportunities and Extension's Role"*

Frederick Stutz, San Diego State University, *"Economic Valuations or Urban Parks in a Freeway Impact Zone Using CVM and TCM: Are the Usual Estimates for Unpriced Resources Valid or Useful?"*

12:00- 1:00 pm -- ***Lunch***

1:00- 2:30 pm -- ***Research Issues in Travel Cost Models***
Cathy Kling, Moderator

Dan McCollum, USDA-Forest Service, Rocky Mountain Field Station, *"A Reverse Gravity Specification for the Travel Cost Model"*

Doug Larson, University of California, Davis, *"Recreation Choices and Implied Values of Time"*

Robert Mendelsohn, Yale University, John Hoff and George Peterson, USDA-Forest Service, and Reed Johnson, EPA, *"The Demand for Package Deals: Measuring Recreation Value with Multiple Destination Trips"*

2:30- 4:00 pm -- ***Environmental Policy Analysis and Applications***
Cathy Kling, Moderator

Anthony Fisher, University of California, Berkeley, *"Evaluating the Impacts of Water Flows, Hatchery Operations, and Harvest Regulations in the California Central Valley Salmon Fishery"*

Richard Ready, University of Kentucky, *"Welfare Measurement and Project Financing"*

Frank Ward, New Mexico State University, *"Hicksian Values of Unpriced Quality: Southwestern Fishing Packages"*

4:00- 5:00 pm -- ***Break***

5:00- 6:00 pm -- ***WRSA Welcoming Reception***

7:00- 9:00 pm -- ***Alternative Time Period for Business Meeting***
(To be decided by member vote on Wednesday morning)

Thursday, February 22

8:00-10:00 am -- ***W-133/WRSA Joint Session on Valuing Environmental and Non-Market Resources***
John Hoehn, Moderator

N.E. Bockstael and K.E. McConnell, University of Maryland, *"Welfare Effects of Changes in Quality: A Synthesis"*

Discussant: O. Bergland, Oregon State University

M. Hanemann and B. Kanninen, University of California, Berkeley, and J. Loomis, University of California, Davis, *"Wildlife Benefit Estimates from a Double Bounded Dichotomous Choice Contingent Valuation"*

Discussant: J.R. Stoll, Texas A&M University

10:00-10:15 pm -- ***Break***

10:15-12:15 pm -- ***Valuing Environmental and Non-Market Resources (Cont.)***

R. Carson, University of San Diego, *"A Multivariate Characterization of Environmental Risk"*

Discussant: J. Bergstrom, University of Georgia

R.G. Walsh, D.M. Johnston, and J.R. McKean, Colorado State University, *"What Can We Learn from 20 Years of Work With TCM and CVM"*

Discussant: K. Boyle, University of Maine

12:15- 1:15 pm -- ***Lunch***

1:15- 3:15 pm -- ***Benefit Cost Analysis Under Uncertainty***
Alan Randall, Moderator

R.C. Bishop, University of Wisconsin, *"Existence Value in Resource Evaluation"*

Discussant: A.C. Fisher, University of California Berkeley

B.G. Colby and D.C. Cory, University of Arizona, *"Contingent Valuation When Benefits are Uncertain"*

Discussant: R. Ready, University of Kentucky

3:15- 3:30 pm -- ***Break***

3:30- 5:30 pm -- ***Benefit Cost Analysis Under Uncertainty (Cont.)***

V.K. Smith, North Carolina State University, *"Valuing Amenity Resources Under Uncertainty: A Skeptical View of Recent Resolutions"*

Discussant: J. Duffield, University of Montana

A. Randall and C.E. Meier, Ohio State University, *"Use Value Under Uncertainty: Is There a 'Correct' Measure?"*

Discussant: P-O Johansson, Swedish University of Agricultural Sciences, Umea

Friday, February 23

8:15-10:15 am -- ***Business Meeting and Election of Officers***
John Hoehn, Moderator

Meeting may be moved to the evening of February 21 by consent of W-133 members)

APPENDIX B

ANNUAL REPORT OF REGIONAL RESEARCH PROJECT W-133

APPENDIX B

ANNUAL REPORT OF COOPERATIVE REGIONAL PROJECTS

Supported by Allotments of the Regional Research Fund
Hatch Act, as Amended August 11, 1955
January 1 to December 31, 1989

PROJECT: Benefits and Costs in Natural Resources Planning (W133)

COOPERATING AGENCIES AND PRINCIPAL LEADERS:

* A. Jubenville, University of Alaska
* W.G. Workman, University of Alaska
* D.A. King, University of Arizona
* W.M. Hanemann, University of California, Berkeley
* A. Fisher, University of California, Berkeley
* K.J. Dawson, University of California, Davis
* W.E. Johnston, University of California, Davis
* C.L. Kling, University of California, Davis
* J.B. Loomis, University of California, Davis
* J.E. Wilen, University of California, Davis
* J. McKean, Colorado State University
* R.G. Walsh, Colorado State University
* J.C. Bergstrom, University of Georgia
* K.C. Samples, University of Hawaii
* E.L. Michaelson, University of Idaho
* K. Boyle, University of Maine
* K. McConnel, University of Maryland
* J. Hoehn, Michigan State University, Chairperson
* B.E. Lindsay, University of New Hampshire
* F.A. Ward, University of New Mexico
* A. Randall, Ohio State University
* D. Badger, University of Oklahoma
* L. Sanders, University of Oklahoma
* D. Schreiner, University of Oklahoma
* O. Bergland, Oregon State University
* W.G. Brown, Oregon State University
* J.R. Stoll, Texas A and M University
* J.E. Keith, Utah State University
* S.C. Matulich, Washington State University
* R.C. Bishop, University of Wisconsin

R. Patrick, Colorado State University
J. Duffield, University of Montana
B. Kristom, UMEA-Sweden
P. Ng, RIT-NY
R. Hageman, San Diego State University
J. Fletcher, West Virginia State University
J. Thompson, BLM-Alaska
L. Schluntz, BOR-Colorado
J. Yager, COE-DA
D. Arrowsmith, FS-R-10
R.M. Martin, FS-R-10
T.C. Brown, FS-RM
J. Hof, FS-RM
D. McCollum, FS-RM
G. Peterson, FS-RM
C. Thompson, NMFS-CA
M. Thomas, Alaska DF&G
F. Bollman, Ag. Ind. Inc, CA
G. Johns, Spec. Econ. Inc, CA

PROGRESS OF THE WORK AND PRINCIPAL ACCOMPLISHMENTS:

The W133 project seeks to (1) conceptually integrate market and nonmarket valuation methods for land and water resources, (2) develop valid methods for adjusting values for resource quality and for marginal tradeoffs across competing resources, and (3) apply such valuation methods to the evaluation of resource outputs. Significant progress was made toward each of the three objectives. A second interim report was edited and produced by Kevin J. Boyle and Trish Heekin of the University of Maine to detail progress on each objective.

Cooperative research by W133 members at different experiment stations was carried out on each objective. Researchers from Alaska, California (Berkeley and Davis), Michigan, Ohio, and Washington developed technical and applied papers for presentation at the Alaska Wildlife Economics Workshop sponsored by the U.S. Forest Service and the Alaska Department of Fish and Game. Michaelson at Idaho organized a session at the annual meeting of the Western Forest Economists that involved W-133 researchers from Georgia and Maine. Berkeley and Davis collaborated on methods development and empirical evaluation of wetlands and wildlife in the San Joaquin Valley in California. Davis, Michigan, and Ohio cooperated on the theory and methods for valuing resource quality changes in the presence of substitution and complementarity. Wisconsin and Maine carried out joint research on the problem of optimal sampling in contingent valuation.

Reports, manuscripts, and work-in-progress were presented and shared among W133 members at a two and one-half day meeting held jointly with the Western Regional Science Association in Molokai, Hawaii, February 20-23, 1990. Twenty-two papers were presented and discussed at this meeting. The agenda, minutes, and list of attendees are attached. A report and proceedings are in preparation.

USEFULNESS OF FINDINGS:

Research results have been applied in natural resources planning at both the state and Federal levels. Specific agencies include the Alaska Dept. of Fish and Game, the California Dept. of Fish and Game, the Maine Dept. of Inland Fisheries, the New Mexico Dept. of Fish and Game, the Soil Conservation Service, the Tennessee Valley Authority, the U.S. Forest Service, the U.S. Environmental Protection Agency, the U.S. Fish and Wildlife Service, and the Utah Division of Wildlife. For example, the California Dept. of Fish and Game plans to evaluate San Joaquin Valley wetland and fishery protection plans using contingent valuation data. Georgia worked with the U.S. Forest Service to develop an aggregate model of the demand, supply, consumption, and value of outdoor recreation is the United States. Michigan worked with the Soil Conservation Service and the U.S. Environmental Protection Agency in applying nonmarket valuation methods to estimating, respectively, the supply of soil erosion reduction by farmers and consumers' demand for food safety. Maine assisted in developing a statewide bald eagle protection plan. New Mexico continued work on a computer simulation model for use by the Department of Game and Fish in evaluating fishery management options.

WORK PLANNED FOR NEXT YEAR:

Work will continue toward the three project objectives and no major changes in project direction or emphasis are planned. Participants plan to continue their close interstation and interagency research relationships. Several project outputs are planned. First, a proceedings for the February, 1990 meeting will be produced and published to document progress in theory and application. Second, a subcommittee has been formed to developed a proposal for reauthorization. Third, the project plans to hold a workshop and business meeting during February, 1991. The February meeting may be held jointly with the Western Regional Science Association. Papers presented at the meeting will be compiled and published as a research report.

RECREATIONAL BENEFITS OF RESERVOIR WATER-LEVEL MANAGEMENT

John C. Bergstrom, H. Ken Cordell, and Deborah Klinko*

*The authors' affiliations are, respectively, Department of Agricultural Economics, The University of Georgia, Athens; Southeastern Forest Experiment Station, USDA Forest Service; and Southeastern Forest Experiment Station, USDA Forest Service. Presented paper at the meetings of the W-133 Regional Project (Benefits and Costs in Natural Resource Planning), Molokai, Hawaii, February, 1990.

Introduction and Background

The Tennessee Valley Authority (TVA) maintains an extensive reservoir system in the Southeastern United States. Most reservoirs were built around the time of World War II. The reservoirs were originally designated primarily for flood control and hydropower. Flood control and hydropower are still priority uses of TVA reservoirs. Over the past 50 years, recreational use of TVA reservoirs has steadily increased. Today, outdoor recreation is one of the major uses of TVA reservoirs.

Management of TVA reservoirs in Western North Carolina and North Georgia for flood control and hydropower involves large fluctuations in water-levels. Water-levels reach a peak in late spring and early summer. The TVA then starts to drawdown water-levels to generate electricity needed to meet high summer demands, and to control floods by establishing excess reservoir capacity in preparation for normally heavy winter and spring rains. Winter and spring rains cause the reservoirs to re-fill until they reach their peak again in late spring and early summer. The cycle of drawdowns and re-filling then repeats itself.

The drawdown of water-levels for flood control and hydropower directly competes with the use of reservoirs for outdoor recreation. Low water-levels in late summer and early fall reduce the suitability of reservoirs for recreational activities such as motor boating, sailing, rowing, water skiing, swimming, and fishing. In recent years, pressure from recreationists and recreation-based businesses to maintain high water-levels throughout the summer has intensified. As a result of this pressure, the TVA is now considering altnernative water-level management proposals.

As a part of the public policy process, the TVA and North Carolina Department of Natural Resources commissioned a study to examine the recreational benefits of alternative water-level management proposals. This paper reports the results of this study. In the next section, the methodology for measuring the recreational benefits of three water-level management alternatives is described. Valuation results are then presented. A summary and conclusions are provided in the final section.

Methodology

Management Alternatives

Four reservoirs in Western North Carolina and North Georgia were included in the study: Lake Chatuge, Lake Fontana, Lake Hiwassee, and Lake Santeetlah. Three management alternatives were examined for each of these lakes. Although there was some slight variation in time periods across lakes, the three management alternatives for each lake were the same. These management alternatives were basically: 1. begin water-level drawdowm one month later; 2. begin water-level drawdown two months later; 3. begin water-level drawdown three months later. Data on the economic value to recreationists of these management alternatives were collected using a contingent valuation method (CVM) survey.

Questionnaire Design

A CVM questionnaire was designed in which the three management alternatives were described using color drawings of the reservoirs at different water-levels.

The current management alternative was described first. Description of the current management alternative in the questionnaire is illustrated for Lake Fontana in Figure 1. Four rows of pictures are shown in Figure 1. These four rows show how Lake Fontana water-levels change throughout the "prime recreational season" (defined roughly as late spring through early fall). Three columns of pictures are also shown in Figure 1. The first column of pictures shows a boat ramp scene. The second column of pictures shows a developed shoreline scene. The third column shows a natural shoreline scene. The pictures shown in Figure 1 are artist renditions of photographs of actual places on Lake Fontana at different water-levels.

After describing the current management situation, the payment vehicle was presented. Recreationists were asked to suppose that everyone using a reservoir would be required to purchase an annual recreation pass for that reservoir. The recreation pass was described in the questionnaire using the graphic display shown in Figure 2.

An annual recreation pass was chosen as the payment vehicle for several reasons. First, the annual recreation pass establishes exclusive rights to the reservoir for recreational use for those who purchase the pass. Thus, it was felt that the annual recreation pass would reduce incentives for free-riding behavior. In addition, recreationists were asked to assume that all reservoirs within a two-hour drive of their home would also require an annual pass. This assumption was needed to force recreationists to value a specific reservoir, without running into the problem of recreationists refusing to pay for a pass because of the existence of "free" substitute sites.

An objective of the study was also to measure net economic value per individual reservoir user (12 years old and older), not per group. One reason

CURRENT MANAGEMENT SITUATION

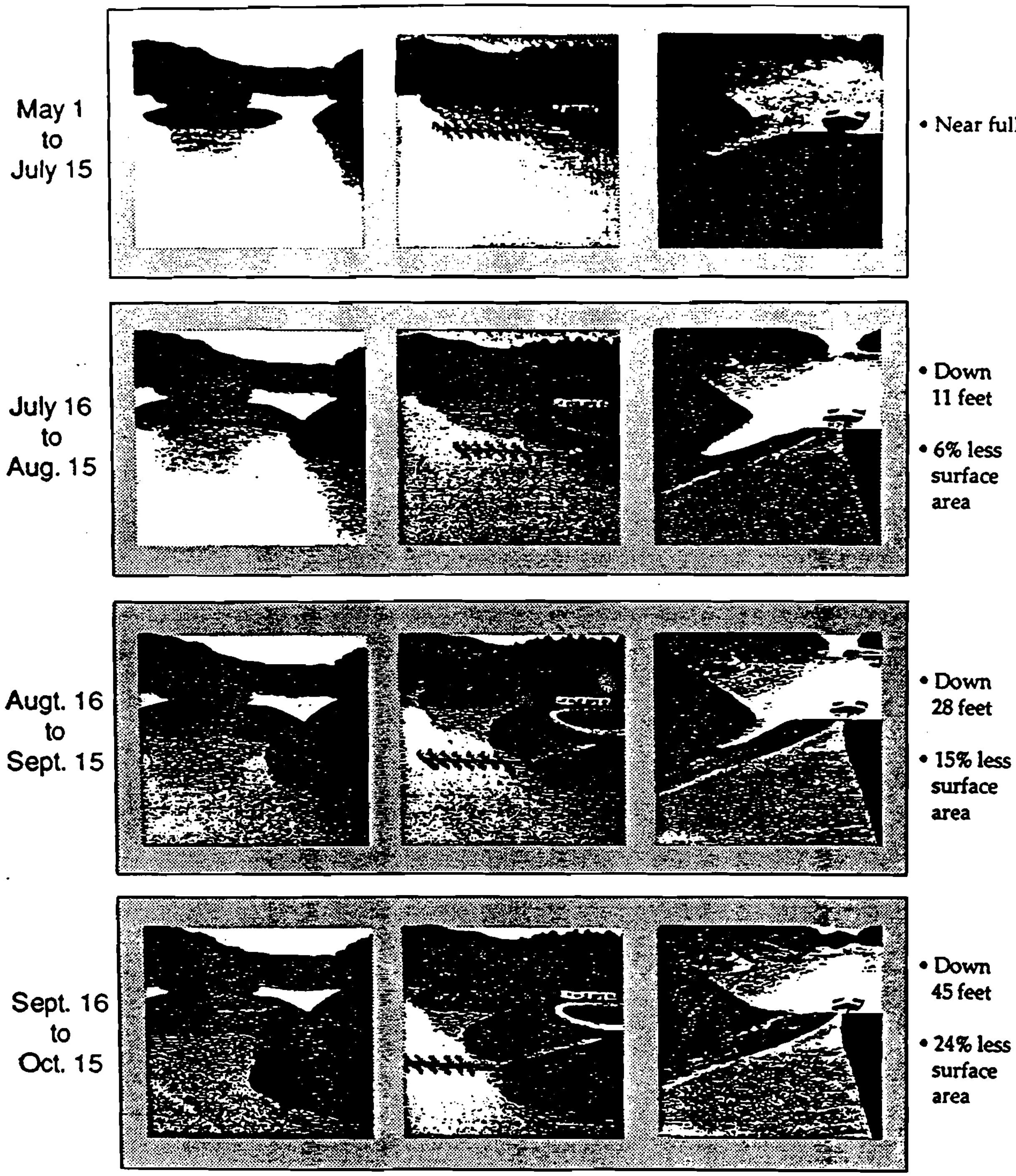

Figure 1. Graphic Display Describing Current Management Situation

Annual Recreation Pass

19 *Lake FONTANA* 89

This pass entitles you to visit and use Lake Fontana as many times as you like during 1989. The pass must be shown each time you visit the lake. This pass can be used only at Lake Fontana, and cannot be used by any persons other than yourself. Each person 12 years old or older must purchase their own annual recreation pass to visit and use Lake Fontana.

____

SIGNATURE DATE

Figure 2. Graphic Display Describing Payment Vehicle

for this objective is that available reservoir use information (e.g., total visitation) is on a per individual basis. In previous CVM studies, it is not always altogether clear if respondents are submitting bids on a per household or group basis or a per individual basis. The exact nature of bids seems especially unclear when children (age 12 to 18) are involved. The annual recreation pass was very specific with respect to the collection of bids for improved water-level management. Thus, the unit of measurement for bids (e.g., per individual 12 years old and older) was clear to both respondents and researchers.

After describing the payment vehicle, bids for the current management situation were elicited by the dichotomous choice or referendum approach. Recreationists were asked if they would continue to use the reservoir if the annual recreation pass were required at a given posted-price. Posted-prices ranged from $1.00 to $300.00. The range of posted-prices was based on previous literature and a pre-test of the survey questionnaire. The exact wording of the willingness-to-pay question is shown in Figure 3. The valuation question was elicited a Hicksian compensating measure of welfare change (Brookshire, Randall, and Stoll; Randall and Stoll).

The next section of the questionnaire described Management Alternative 1. Management Alternative 1 was described with color drawings or pictures of a reservoir at different water-levels following the same type of graphic display used to describe the current management situation. The graphic display used to describe Management Alternative 1 for Lake Fontana is shown in Figure 4. As shown in Figure 4, Management Alternative 1 for Lake Fontana involves holding water-levels at "near-full" for about one month longer in the summer as compared to the current management situation.

CURRENT MANAGEMENT SITUATION

Suppose that current management of water levels at Lake Fontana as shown on PAGE 2 (far left) is continued into the future. Also, suppose that you had to purchase the annual recreation pass described on PAGE 3 in order to use Lake Fontana (please review description of annual pass on PAGE 3).

Q-2 If the annual pass cost $____ per year, would you continue using Lake Fontana? (Circle ONE number.)

1 NO

2 YES ⇨ With this pass, about how many trips would you take to Lake Fontana during the next 12 months?

________TRIPS

Figure 3. Valuation Question for Current Management Situation

MANAGEMENT ALTERNATIVE 1

Keep lake near full about one month longer

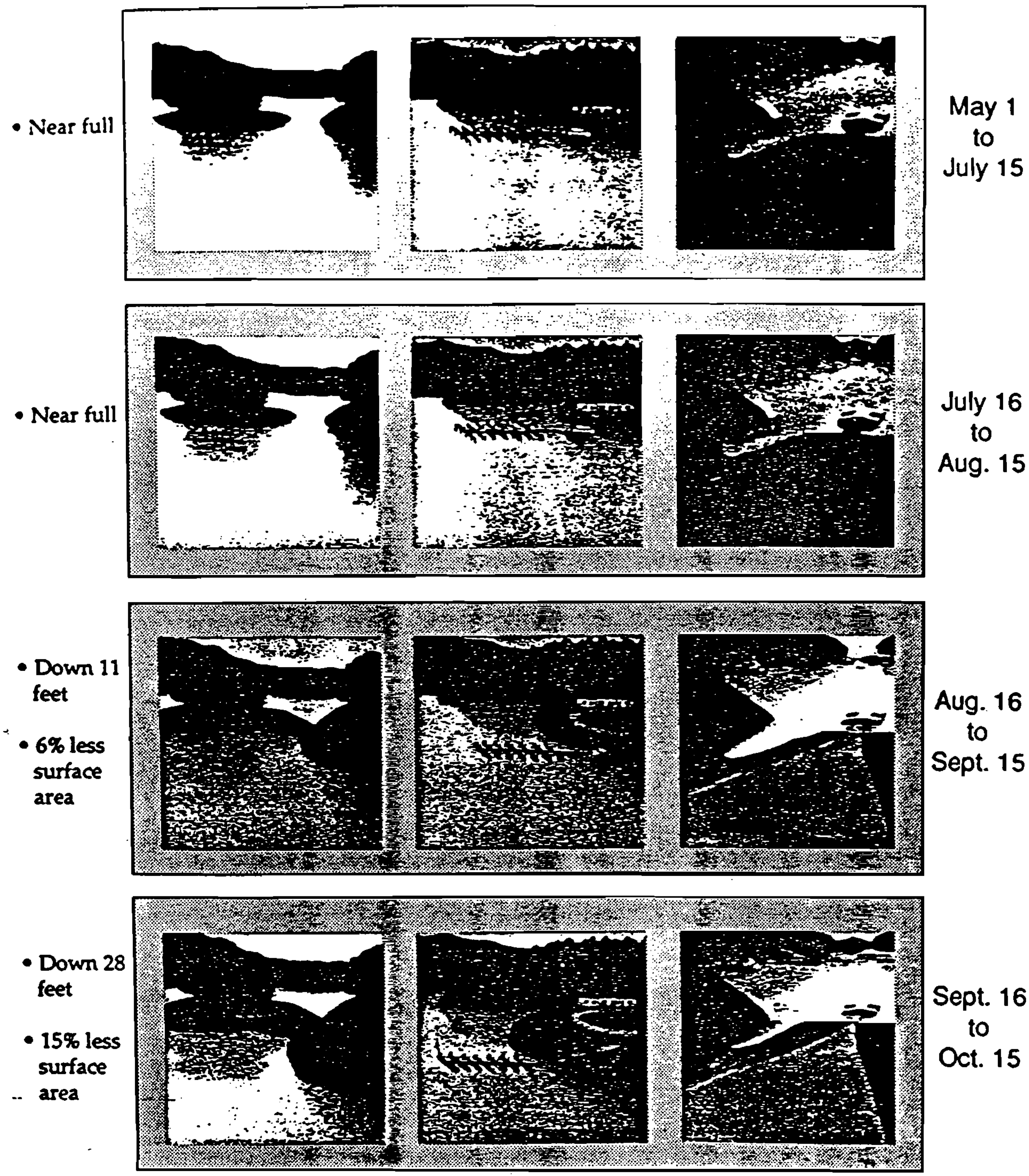

Figure 4. Graphic Display Describing Management Alternative 1

Following the description of Management Alternative 1, recreationists were asked to submit a bid for the management alternative. Bids were again collected using a dichotomous choice question which elicited a Hicksian compensating welfare change measure. The exact wording of the valuation question for Lake Fontana under Management Alternative 1 is shown in Figure 5. After collection bids for Management Alternative 1, Management Alternative 2 was described and bids for this management alternative were elicited.

Finally, Management Alternative 3 was described and bids for this management alternative were elicited. Management Alternative 2 and Management Alternative 3 were described with color drawings or pictures employing the same type of graphic display used for the current management situation and Management Alternative 1. Bids for the last two management alternatives were elicited following the same dichotomous choice question format used for the current management situation and Management Alternative 1.

In order to encourage respondents to compare each management alternative to the current management situation in a series of pairwise comparisons, the questionnaire was designed such that the current management situation description would always be folded-out to the left. As respondents turned the questionnaire pages, the description of each management alternative would come to rest next to the folded-out current management situation description. On the page opposite to the management alternative description on the right, willingness-to-pay questions for the management alternative were asked. Thus, when submitting a bid for a management alternative, respondents could compare the management alternative to the current management situation without flipping pages. This questionnaire design feature is illustrated in Figure 6.

MANAGEMENT ALTERNATIVE 1

Because Lake Fontana is a man-made lake, the water level can be changed. Suppose the water levels were kept higher 1 month longer than was shown for current management of the lake on PAGE 2. The pictures on PAGE 5 show this new management alternative, which we call Management Alternative 1. Please take a moment to compare water levels under Management Alternative 1 (PAGE 5) with Current Management (PAGE 2, far left).

For the questions below, suppose again that you had to purchase the annual recreation pass described on PAGE 3 in order to use Lake Fontana. Please review the description of the pass on PAGE 3.

Q-5 If the pass cost $____ per year and water levels are managed as shown for Management Alternative 1 (PAGE 5) instead of how water levels are currently managed (PAGE 2), would you continue using Lake Fontana? (Circle ONE number.)

1 NO

2 YES ⇨ With this pass and Management Alternative 1, about how many trips would you take to Lake Fontana during the next 12 months?

________TRIPS

Figure 5. Valuation Question for Management Alternative 1

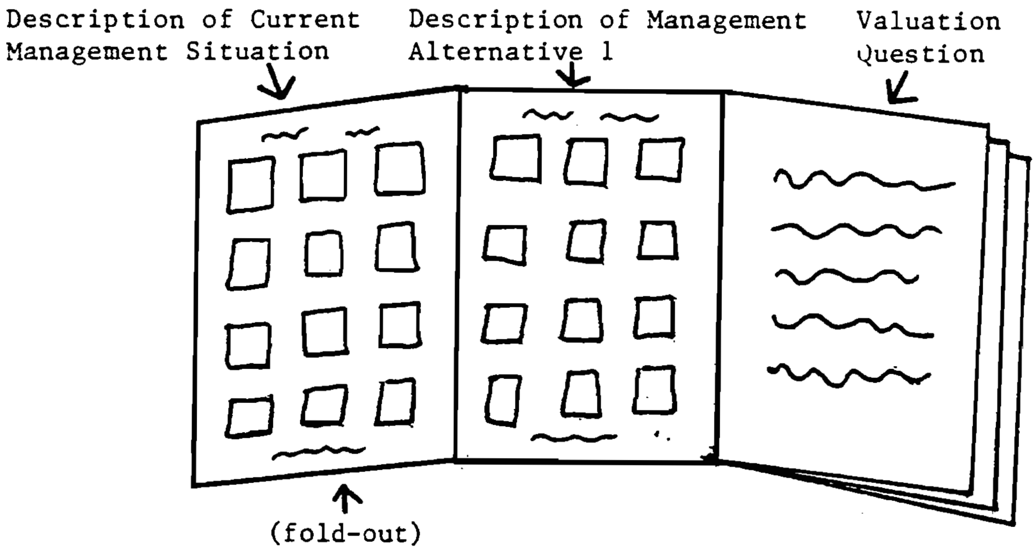

Figure 6. Illustration of Questionnaire Design Feature for Encouraging Pairwise-Comparisons of Management Alternatives with Current Management Situation

Survey Procedures

Names and addresses for the CVM survey were obtained from an extensive on-site survey of recreational users. Throughout the spring and summer of 1988 and 1989, interviewers were stationed at various access points at each of the study reservoirs. Interviewers conducted exit interviews of a stratified random sample of users. Strata included boaters vs. non-boaters, day users vs. overnight users, and fishermen vs. non-fishermen. During the exit interviews, interviewers asked questions about general recreation preferences, participation, and travel patterns. At the end of the interview, respondents were asked to provide their name and address for a follow-up mail questionnaire (the CVM survey instrument). Very few respondents refused to provide their name and address.

In the fall of 1988 and 1989, a cover letter and questionnaire were sent to all people who provided their name and address in the on-site interview. The conduct of the mail survey followed general procedures specified by Dillman. Approximately one week after the first questionnaire mailing, a follow-up post card reminder was sent to all people in the sample. After three weeks, a follow-up letter with a replacement questionnaire was sent to all non-respondents. Because of budget and time constraints, no further follow-ups were conducted.

Estimation of Mean Willingness-to-Pay

Mean willingness-to-pay was estimated using standard procedures described by Hanemann, and Sellar, Chavas, and Stoll. The first step was to estimate a logit function:

(1)

$$Y = \frac{1}{(1 + \exp(B_o - B_1P + B_2X))}$$

where, Y = 1 if a respondent answered "yes" to the valuation question, Y = 0 if a if a respondent answered "no" to the valuation question, P = posted-price, X = vector of preference, reservoir, and management variables, and B_o, B_1, and B_2 are parameters to be estimated. The X-vector variables appearing in Equation 1 are defined in Table 1. After estimating Equation 1, mean willingness-to-pay was estimated by the integral:

(2)

$$MWTP = \int_0^{Pmax} \frac{1}{(1 + \exp(b_o - b_1P + b_2X))} dP$$

where, MWTP = mean willingness-to-pay per individual, Pmax = maximum posted-price ($300), and b_o, b_1, and b_2 are estimated parameters.

Change in Aggregate Willingness-to-Pay

In order to estimate the change in aggregate willingness-to-pay resulting from a change in water-level management, it was necessary to estimate the change in reservoir use that would occur under each management alternative. The change in trips to a reservoir resulting from a change in water-level management was estimated using two methods. First, in the CVM questionnaire, recreationists were asked to estimate the number of trips they would take to a reservoir under each management alternative. Second, expert panel surveys were conducted for each reservoir.

VARIABLE	PARAMETER ESTIMATE (STANDARD ERROR)
INTERCEPT	2.6557 (.3024)***
LPRICE	-0.8651 (.0367)***
LSPEND	0.0921 (.0460)**
SEX	0.4117 (.1216)***
R1	-0.4541 (.1364)***
R2	-0.6746 (.1494)***
R3	-0.1267 (.1271)
S1	0.2592 (.1403)*
S2	0.5914 (.1398)***
S3	0.8134 (.1406)***
N	2487
McFadden R^2	.42

***SIGNIFICANT AT .01 LEVEL

**SIGNIFICANT AT .05 LEVEL

*SIGNIFICANT AT .10 LEVEL

Table 1. Logit Function Parameter Estimates, Willingness-to-Pay for Water-Level Management Alternatives at TVA Reservoirs, 1988-89.

For the expert panel surveys, the North Carolina Department of Natural Resources in cooperation with the TVA provided a list of names of local people who were highly familiar with visitation patterns for each reservoir. The "experts" for a particular reservoir were asked to attend a meeting where they would be asked to provide information on visitation to the that reservoir under different management alternatives. About 20 individuals attended each of the four reservoir expert panel sessions.

During the expert panel session for a particular reservoir, slides were shown of the current management alternative and each of the three water-level management alternatives. The slides used in the expert panel session were slides of the graphic displays used in the CVM questionnaire to describe the current management situation and the management alternatives. After viewing the slides and asking questions about the management alternatives, the panel of experts was asked to provide estimates of the change in total visitation under each management alternative. The panel was instructed to consider two sources of increased visitation: 1. increased visits from current reservoir users; and 2. increased visits from people who do not currently use the reservoir, but would be induced to use the reservoir given a change in water-level management.

Because the CVM data accounts only for increased visitation from current users only, changes in visitation estimated from these data were considered to be "lower bound" estimates. Because the expert panel data accounts for increases in visitation from both current and new users, changes in visitation estimated from these data were considered to be "upper bound" estimates. The "most expected" changes in visitation were estimated by taking the arithmetic means of the CVM data estimates and the expert panel data estimates. These changes in visitation were converted to changes in total users (by using estimates of mean trips per user from the CVM data), and then combined with estimates of mean willingness-to-pay per individual to estimate the change in aggregate willingness-to-pay under each management alternative.

Results

Survey Response Rate

The total sample for the 1988 season was 801. A total of 388 useable questionnaires were returned for a response rate of 48.4%. The total sample for the 1989 season was 770. A total of 460 useable questionnaires were returned for a response rate of 59.7%. The increased response rate for the 1989 season may be attributable to: 1. greater awareness of the water-level management issue resulting from increased media attention; 2. improved water-level conditions at the reservoirs resulting from abnormally high spring and summer rainfall. The overall response rate across both seasons was 54%.

Parameter Estimates

The logit function specified in (1) was estimated by maximum likelihood. The parameter estimates are shown in Table 1. In Table 1, LPRICE is the natural logarithm of the posted-price variable and LSPEND is the natural logarithm of the recreational spending variable. LSPEND has an expected negative sign and is statistically significant at the .01 level. LSPEND has an expected positive sign and is statistically significant at the .05 level. SEX has a positive sign and is statistically significant at the .01 level. The positive sign on SEX indicates that males are willing-to-pay more for higher water-levels than females.

Each of the reservoir indicator variables has a negative sign. These negative signs suggest that compared to the base reservoir (Lake Chatuge), the net economic value of higher water-levels is lower at the other three reservoirs. The indicator variable for Lake Hiwassee (R1) and Lake Santeetlah (R2) are statistically significant at the .01 level. Each of the management alternative indicator variable has a positive sign as expected. The indicator variable for Management Alternative 1 is statistically significant at the .10 level. The indicator variables for Management Alternative 2 (S2) and Management Alternative 3 (S3) are statistically significant at the .01 level.

Willingness-to-Pay Per Individual

Annual mean willingness-to-pay (WTP) per individual (12 years old and older) calculated from (2) are shown in Table 2. Mean WTP increases steadily over the three water-level management alternatives. Mean WTP is greatest for Lake Chatuge and lowest from Lake Santeetlah. Lake Fontana has the second highest mean WTP, and Lake Hiwassee has the second highest mean WTP. These results are consistent with intuition. Lake Chatuge and Lake Fontana are more developed than the other reservoirs and most likely attract users who are more willing and able to pay for higher water-levels (e.g., out-of-state residents with greater preferences for water-level dependent activities such as water skiing). Lake Hiwassee and Lake Santeetlah are largely undeveloped and attract primarily local users who engage in activities such as fishing which are less water-level dependent.

	ANNUAL WTP PER INDIVIDUAL			
	Current Management (Baseline)	Management Alternative 1	Management Alternative 2	Management Alternative 3
1. Chatuge	$47.95	$57.44	$72.65	$82.47
2. Fontana	43.80	52.62	65.95	76.17
3. Hiwassee	34.48	41.70	52.80	61.48
4. Santeetlah	29.24	35.48	45.19	52.86
Average Across All Lakes	$38.87	$46.81	$59.15	$68.24

Table 2. Annual WTP Per Individual for Recreation at TVA Reservoirs Under Different Water-Level Management Alternatives, 1988-89.

Across all reservoirs, mean WTP for the current management situation is estimated at $38.87 annually. Mean WTP for Management Alternative 1 across all reservoirs is estimated at $46.81 annually. Mean WTP for Management Alternative 2 across all reservoirs is estimated at $59.15 annually. Mean WTP for Management Alternative 3 across all reservoirs is estimated at $68.24 annually. These valuation estimates appear reasonable, especially considering that they represent net economic per individual 12 years old and older.

Aggregate Willingness-to-Pay

Aggregate baseline WTP, and the change in aggregate WTP under each management alternative, are shown for each reservoir in Table 3. The change in aggregate WTP under Management Alternative 1 ranges from $409,902 annually for Lake Santeetlah to $1,781,957 annually for Lake Chatuge. The change in aggregate WTP under Management Alternative 2 ranges from $967,982 annually for Lake Hiwassee to $4,642,690 annually for Lake Chatuge. The change in aggregate WTP under Management Alternative 3 ranges from $2,028,976 annually for Lake Hiwassee to $7,587,424 annually for Lake Chatuge.

The sums of the change in aggregate WTP across all reservoirs are shown in the last row of Table 3. The total change in aggregate WTP across all reservoirs under Management Alternative 1 is estimated at $4,360,608 annually. The total change in aggregate WTP across all reservoirs under Management Alternative 2 is estimated at $9,819,021. The total change in aggregate WTP across all reservoirs under Management Alternative 3 is estimated at $17,648,092 annually.

In a recent publication, the TVA reports that Management Alternative 3

	Baseline Aggregate WTP	CHANGE IN AGGREGATE WTP		
		Management Alternative 1	Management Alternative 2	Management Alternative 3
1. Chatuge	$6,831,688	$1,781,957	$4,642,690	$7,587,424
2. Fontana	$5,577,732	1,484,777	3,082,993	6,835,753
3. Hiwassee	$1,392,007	683,972	976,982	1,404,971
4. Santeetlah	$2,524,140	409,902	1,116,356	1,819,944
TOTAL	$16,325,567	$4,360,608	$9,819,021	$17,648,092

Table 3. Changes in Aggregate WTP for Recreation at TVA Reservoirs Under Different Water-Level Management Alternatives, 1988-89.

(which delays the start of the summer drawdown by three months) would result in a loss of $25 million annually in lost hydropower generation (Tennessee Valley Authority). The loss in hydropower generation is quite comparable to the gain in recreational benefits which are estimated at approximately $18 million annually. In fact, the gain in recreational benefits is likely to be higher than the loss in hydropower benefits because the $18 million estimate for recreation accounts for only four reservoirs in the TVA system, whereas the $25 million estimate for hydropower accounts for all reservoirs in the TVA system.

Summary and Conclusions

Management of TVA reservoirs for hydropower and flood control in Western North Carolina and North Georgia involves large drawdowns of water-levels starting about mid-summer. These drawdowns reduce the suitability of reservoirs for outdoor recreation. As a result pressure from recreationists and the recreation-dependent business community, the TVA is considering management alternatives for holding water-levels higher during the prime recreational season

A study was conducted to measure the recreational benefits of three water-level management alternatives which corresponded roughly to: 1. delaying the start of the summer drawdown by one month (Management Alternative 1); 2. delaying the start of the summer drawdown by two months (Management Alternative 2); and 3. delaying the start of the summer drawdown by three months (Management Alternative 3). It is estimated that Management Alternative 1 would result in an increase in aggregate recreational benefits of about $4.4 million annually. Management Alternative 2 would result in an increase in aggregate recreational benefits of about $9.8 million annually. Management Alternative 3 would result in an increase in aggregate recreational benefits of about $17.6 million annually.

The gain in aggregate recreational benefits from holding higher water-levels longer in the prime recreational season appear to compare closely to the associated loss in hydropower benefits. Thus, from a benefit-cost analysis, delaying the start of the summer drawdown may be justified from an economic efficiency (e.g., national economic development) standpoint. However, any firm conclusion about the economic desirability of the three water-level management alternatives considered in this study cannot be made without a full-blown benefit-cost analysis that accounts for all relevant impacts.

The application of the contingent valuation method to measure the recreational benefits of reservoir water-level management was encouraging. Further research is needed, however, to validate the results. Further research is also needed to improve techniques for measuring changes in visitation resulting from changes in water-level management. Two potential techniques were explored in this study: 1. direct questioning of recreationists; and 2. expert panel sessions.

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RECREATIONAL ACCESS TO PRIVATE LAND:

PROBLEMS, OPPORTUNITIES AND EXTENSION'S ROLE

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RECREATIONAL ACCESS TO PRIVATE LAND:

PROBLEMS, OPPORTUNITIES AND EXTENSION'S ROLE

James E. Miller

Abstract

Recreational access to private lands and waters has traditionally been viewed by many public users as a "right", even though for those who own a piece of land, the members of the public who availabe themselves of that "right" without permission of the landowner are viewed as trespasssers. This difference in viewpoint, has in recent years led to many problems, created divisive conflicts and stimulated increased efforts by politicians to enact more regulatory and statutory liability laws. Dependent on the perspective of the landowner, the availability of access to the public, the sate laws and their enforecability, the attitude about access to, and demand by the public for private land recreational access, and the supply of alternative access to public lands, all of these factors can effect decision-making as to whether it is a problem or opportunity. The Cooperative Extension System, (Extension Service, U.S. Department of Agriculture and State Cooperative Extension Services' across the nation) because of its three-way partnership (federal, state and county, people and funding) and its direct ties to the Land Grant (1862 and 1890) Institutions clearly has a role to serve both the private landowner and the public on this issue through its research-based educational programs.

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INTRODUCTION

When public recreational users become liabilities to private landowners and managers, unlike managers of public lands who also have recreational user problems, the private landowner has not only stronger ownership rights but can also use the laws of the land and other means to prohibit access to their property. Whatever the justification, increasingly privately owned lands in much of the United States are being posted and public access to private lands for recreational use is becoming more limited. For those who might find this difficult to understand from the landowners perspective, I suggest that if you do not own a parcel of rural land of 20 acres or larger, which some segment of the public wants to gain access to, for whatever type of recreational use, especially if it does not have someone living on it, just ask a private landowner who does.

What this boils down to from the landowners perspective is that many of them no longer are faced with an occasional public user, or neighbor or friend who comes by and asks for permission to enter their land for recreational use. In some regions of the nation, many landowners are constantly besieged either with trespassers on ATV's, or hunters, fishermen or poachers if they have suitable habitats, or "non-consumptive" users, some of whom even may request permission, who trek across their fields or forests in search of expanding their bird lists, to locate some rare plant, or to hunt, fish or otherwise commune with nature. Even worse are those who drive out from nearby cities to drop their unwanted dogs and cats, or their garbage. Clearly, these problems are growing, particularly in the Eastern U.S. where in many counties rural lands with high potential recreational use are being gobbled up dramatically by urban sprawl, industrial development, shopping centers and other developments to meet the growing populations needs and desires.

From the private landowner or managers perspective, not only has there been a change in the demography and attitudes of the public but also a change in the attitudes of many of those who are owners and stake-holders of private lands.

Increasingly the attitude of many of these private landowners is that if the incentives of making recreational access to the public available do not outweigh the disincentives, few of them now, or in the future can afford to continue to make such access available. Many private landowners today do not make their living primarily from the land and this fragmentation of non-farm and non-resident ownership is having significant impact on some outdoor recreational activities and access. More private lands are being closed to recreational access each year because of the following five reasons: (1) trespass, (2) inability to control use, (3) potential liability, (4) unfavorable experience with recreational users, and (5) the disincentives of open access to public use in most cases, far exceed the incentives.

SITUATION

Recent estimates indicate that private landowners presently own and control approximately 2/3 of the land and waters in the contiguous U.S. Of the total lands and waters in the U.S. which could provide recreational use, approximately 71 percent of all forest lands, 74 percent of all wetlands, and 64 percent of all rangelands are privately owned (Jahn 1989). Admittedly, the situation and magnitude of the problem is different in some regions of the country, based on supply and demand. For example, although over 63 percent of the people in the U.S. live in the east, only 9 percent of all public lands are found in the east. Obviously, then approximately 37 percent of the population lives in the west, but 91 percent of the public lands in the U.S. are found in the west. From the standpoint of public access supply and demand, what kind of opportunities might this offer for eastern landowners? Yet public lands as vast as they might appear even in the west, cannot and will not meet all future needs for public recreation.

Not only is much of this public land not readily available to the majority of the U.S. population, but even if it is, it may not offer the quality of experience that many of these people want. Thus the situation we find ourselves faced with is an increasing human population with a expanding need for goods and services which are causing a progressive reduction of available lands for recreational use. To provide the natural resource base that the growing populace would like to have access to for recreational use we must stimulate private landowners to examine the opportunities. This public demand for access to and use of natural resources for outdoor recreation is increasing and dynamic over time as a consequence of changing social, economic and cultural factors, and the individual desires of recreational users.

The public desire and willingness to pay for recreational access and related goods and services is well documented and accepted for many outdoor activities, whereas for others the perspective of many people is that they expect it to be available at no charge because it has always been free and available in the past. A good example of this controversy is the growing trend in some parts of the U.S. for private landowners to charge fees for recreational access to their lands and waters for hunting, fishing or related wildlife recreational use.

Apparently the perspective of some who expect to gain access to private lands for such use is that access should be free because wildlife is publicly owned. The paradox is that, yes wildlife is owned by the public, yet there is an investment cost incurred by the landowner to conserve and or manage the habitat that sustains the wildlife. Most people who pursue outdoor recreational access to a ski resort even on public lands, expect to incur costs to gain access to the area and to utilize the facilities provided and maintained by the owner. Yet many of these same people object to paying a private landowner for access to hunt or fish, or birdwatch or go hiking on private land. They obviously fail to understand or ignore the fact, that the landowner incurs direct or indirect expenses, or opportunities lost, in managing their land so that it supports wildlife populations or affords the natural beauty one seeks on a hiking trail.

Admittedly, many landowners in the past, depending on what they used their land for, considered wildlife primarily as a by-product of other land management efforts. Most of them also failed to consider that wildlife had any value if they decided to alter their management in a manner that would eliminate the habitat which sustained wildlife. Some even considered eliminating wildlife habitat because of crop losses wildlife caused. The result in some areas, is mile after mile of corn or wheat fields or even more permanent, mile after mile of houses, townhouses, shopping centers or industrial development. If you live in an area where either of these scenes are not common I envy you. However, the point is two fold. Not only has such changing land use reduced the amount of lands which are capable of sustaining wildlife, and other outdoor recreational activities, in other areas it has made private landowners realize that there is an increasing demand for wildlife associated recreation which their land potentially offers. It also helps them to understand that wildlife does in fact have some benefit other than intrinsic value. For many of them, especially in the south, southwest and a few other areas around the country, the realization that there is a willingness to pay for recreational use by some of the public has resulted in a significant difference in how they manage their lands. It has also made a difference in how they value wildlife and recreational users.

PROBLEMS

What are some of the problems or disincentives private landowners are faced with regarding recreational access by the public? As a private landowner myself, let me list just a few associated with public recreational access and I expect many of you could add to this list.

1. Periodic property damage and other costs associated with trespassers without respect for the land or its owner. Costs of repair to land and facilities are often significant and time consuming.

2. Hazards to family, workers, livestock or facilities from use by recreationists, e.g. random shots from hunters, livestock being scared or harassed or eating trash left by recreationists, etc.

3. Bother and frustration of trying to deal with users while working or trying to remove trespassers using the land without permission, gates left open, fences cut, etc.

4. Costs of potential liability claims even from trespassers, insurance, posted signs, and other costs associated with trying to gain control over who is using their land.

5. Management costs, fencing, gates, wildlife damage to crops and trees, habitat sustainability, road maintenance, etc.

6. Modification of land use practices to accommodate users needs, or to avoid having some trespasser or guest being in jeopardy while using the property.

7. Frustration and costs of trying to obtain compensation from recreationist caused damage.

8. Loss of the desire to be a good steward when others reap most of the benefits without any compensation to the owner.

9. Opportunities lost when the owner or their friends want to recreate only to find that trespassers have already taken the surplus game or fish, or otherwise reaped the benefits of the owners management, or damaged the property preventing enjoyment of the resources.

10. No one to turn to for help when paying the bills or cost-sharing to improve the recreational opportunities. Obviously, there are numerous others that could be added but these examples are real. One encounter or confrontation between a landowner and a belligerent trespasser who thinks they have the right to do as he or she pleases is generally enough to cause a landowner to take further action.

These problems or disincentives which most of you are probably familiar with, cause many landowners to be turned off completely to allowing recreational use of their land by the public. Others, however, if they live in an area where it is socially acceptable, where demand is high, and if they have enough land to make it feasible or can join a landowners cooperative, have begun to look at the problem as a potential opportunity. Two other factors, however are critical, one is that they can adapt to dealing with recreationists and, two that they can somehow control who is using their lands and for what purpose.

OPPORTUNITIES

Having delineated some of the problems and disincentives of free recreational access to private lands from the landowners perspective, lets now examine some of the fee access opportunities for the landowner and the benefits to both recreationists and for the public good. The following lists are compiled partially from personal experience, from review of annual accomplishment reports and publications of State Cooperative Extension Service (SCES's), and from recent conferences, proceedings and other published literature on the subject.

Opportunities for the Private Landowner

1. Another alternative for producing income which can be made compatible with other existing operations and land use.
2. A way to gain better control of who is using their lands, at what times use is allowed, and for what purpose.
3. Increased incentives to manage for sustainability of a strong and diverse natural resource base, and more diversity of cash flow.
4. Reduced damage from recreational users and capability to obtain compensation from these users.
5. Reduced frustration from trespassers or others once it is known that land use is restricted to fee access use only.
6. Reduced hazards to workers, livestock and property from recreational users because of better control.
7. Increased income to offset management costs and liability costs.
8. Improved attitudes about recreationists and investments in natural resources management.

9. Satisfaction of being a better steward of the land and making it pay dividends. Also, a feeling of increased property value for the future.

10. Generally if a landowner begins to manage for fee access, they learn that keeping records is important and depending on the enterprise, these paying recreationists develop an increased interest in the land, and a better appreciation of the landowners objectives.

Benefits to Recreationists Who Pay.

1. A place to recreate where they know they are welcome and can enjoy an outdoor experience without competition from too many other people.
2. A sense of satisfaction from paying their own way and a proprietary interest in how the lands are managed.
3. A greater interest in ethical, responsible behavior, because they plan to return.
4. Improved landowner-recreationists relations.
5. An opportunity to cooperate with the landowner for enhanced recreational benefits.
6. A feeling of contributing positively toward helping the landowner sustain the natural resources they value in an outdoor recreational experience.
7. Increased interest in using the opportunity from their investment.
8. An improved feeling of safety and comfort because they come to know the place and how to use it without causing a problem for the landowner.
9. Better opportunity to relax and to involve family and friends in their recreational activities without competing with other public recreationists for space, or access.
10. An increased sense of responsibility and stewardship by the recreationist.

Benefits to the Public Good From Fee Access For Recreational Use.

1. More lands and waters being better managed to sustain natural resources for potential use by present and future generations of recreationists.
2. Reduced competition on some public lands as more private landowners see

the benefits of fee recreational use and improve the quality of experience and services afforded.

3. Reduced conflicts between landowners and recreationists and increased economic benefits to rural communities.

4. Increased appreciation by private landowners that diversity of operations and maintenance of a viable natural resource base is of long-term benefit to them as well as to the public.

5. Increased appreciation by the public that helping private landowners maintain lands and waters in a condition that is beneficial to wild living things is in the nations best interest.

6. That more recreational access for public use and enjoyment is available, if we are willing to compensate the private landowner, as demand continues to increase and access decreases to those unwilling to pay for it.

7. Increased knowledge and awareness that many private landowners are responsive to appropriate incentives and are willing to increase access to their lands for recreational use by responsible users.

8. Increased appreciation for the fact that there are costs associated with the management of lands and waters for recreational use on private lands as well as on public lands.

9. Recognition of the fact that access to and use of natural resources on private lands and waters is a privilege and an opportunity, not an inalienable right.

10. It will also be to the public good when we recognize that paying for the privilege of access to private land for wildlife associated recreation is not selling wildlife, it is compensation for the landowners investment and costs, and for the opportunity to enjoy recreation on his or her land.

Now admittedly, those who oppose this would disagree with some of these benefits, however, as previously noted, unless they own land and have dealt with the disincentives, they may not recognize the plight of private landowners. For example, the issue of paying fees to private landowners for hunting and fishing opportunities is a controversial and emotional issue in some parts of the country. Some people object to private landowners charging access fees or leasing land for hunting, fishing or other outdoor recreational use. They contend that fish and wildlife belong to the public and that access for the pursuit of these species, even on private lands and waters should be free.

Farming, ranching and forestland management on private lands are businesses. Altering food and fiber production or otherwise changing land use and management practices to accommodate wildlife, fish and recreational users requires monetary investments, labor and other considerations. Free hunting and other recreational use on private lands runs counter to the present economic facts of life for many landowners and managers (Jahn 1989). In fact, a precedent for changing the perspective about wildlife management on private lands and the idea of landowner incentives was set by Aldo Leopold and the committee on Game Policy in the 1930 American Game Policy, (WMI, 1976). This committee concurred and reported that--the best way to encourage private landowners to manage for wildlife was to: "Compensate the landowner directly or indirectly for producing a game crop and for the privilege of harvesting it".

This statement is even more pertinent and applicable today than when reported by the 1930 American Game Policy Committee. A recent study, (Cordell, et.al 1988) of 16,000 private landowners in 48 states, revealed the growing importance of recreational lease and fee access. It reported that 95 percent of those surveyed considered income from recreational access to their lands as an important reason for owning these lands and waters. In 1987, 7.3 percent of these owners with about 70 million acres of land, were presently leasing or otherwise receiving income from some portion of their holdings in return for allowing recreational use by others. Some bottomline conclusions drawn by the investigators after concluding this study revealed that: "Conservation and habitat improvement is significantly greater on those private lands being leased; fee access recreation may help owner incomes and encourage them to conserve natural resources, and; demand for recreational access to private lands is still rising".

In a final return to the contention by some people that outdoor recreational use, including fishing and hunting is free, lets examine briefly some data from the "1985 National Survey of Fishing, Hunting and Wildlife Associated Recreation (FWS, USDI 1988). It reported that a record 141 million Americans age 16 and older participated in wildlife associated recreation during 1985, and spent over $55 billion in these pursuits. Further data (FWS, USDI 1987) reported that in 1986, expenditures by hunters and fishermen for State licenses and permits was a record $624 million, and they spent another record $248 million in Federal excise taxes on sporting goods and ammunition. However, as noted from the 1985 survey, only 4 percent of the hunters, and 2 percent of the fisherman reported paying fees for access to private lands. Therefore, few of the total of over $17 billion in expenditures by hunters and fishermen were received by those private landowners and managers who own and manage over 2/3 of the wildlife habitat. It is interesting to note that 3 percent of the non-consumptive recreationists reported paying fees for access to private land, and 15 percent paid fees for public lands access. Further data reported in the 1985 Survey indicated that 82 percent of all hunters, over 13.7 million, spent all or a major part of their hunting time in 1985 on private lands. In fact, the largest group of hunters, 8.5 million or 51 percent of all hunters hunted on privately owned lands, but not on public lands during 1985.

EXTENSIONS ROLE

The Cooperative Extension System, established and guided by the Smith-Lever Act of 1914, subsequent amendments, and the Renewable Resources Extension Act of 1978, as reauthorized and amended, provides an effective educational system involving a unique partnership of federal, state and local governments, funding and people. Through its ties to the land-grant system of colleges and universities (1862 and 1890), Extension provides informal non-credit education, primarily outside the classroom for adults and youth, as well as continuing education programs for professionals. As a grassroots directed program, it features the presentation of educational programs based on research findings from the complete resources of the land-grant institutions and from other credible federal and state agencies. Stated in simpler terms, it provides factual, objective, practical, problem-centered, and people-oriented information to enable people to help themselves--solve problems, make decisions, and take advantage of new opportunities (Miller 1981).

Those Extension educational programs in the natural resources area play a major role in helping private landowners, managers, and users to understand and adapt current technologies to ensure the sustained, productive capability of the nation's natural resource base. They also interact with and complement other pertinent programs, initiatives and priorities of the land-grant universities consistent with the mission of Extension. Cooperation with other federal and state agencies, organizations and support groups on programs of mutual interest to assist private landowners, managers and users is critical to Extensions effectiveness in natural resource programming.

What then is Extension's role in the area of recreational access to private lands? Although, presently there is no official Extension policy on this issue, if I were given the responsibility to develop such a policy it would be stated as follows: "That the Cooperative Extension System in coordination with Land-Grant University programs would provide private landowners and managers with educational information and technical assistance, in cooperation with appropriate state and federal agencies on management strategies to enhance and sustain productive natural resources on their lands. These multi-disciplinary educational programs will also provide objective information on potential incentives and disincentives, costs/benefits, risks/benefits, and marketing associated with managing access, (either free, or at a cost to the user) for recreational use on their lands, if the owner or manager is considering such management as a potential opportunity or preferred option".

Since I am most familiar with those Extension programs relating to natural resources and specifically those related to wildlife and fisheries, let me share some examples of recent educational accomplishments, programs and informational materials which relate to recreational use and fee access. One effort which I was involved with directly for several years, along with other committee members in the public policy area was the Wildlife Resources Committee of the Great Plains Agricultural Council (GPAC). This committee because of the controversy surrounding fee access for recreational use in some of the Great Plains States was asked in 1986 to develop a position statement for the GPAC to consider. This effort resulted in the following Position Statement of the GPAC on Wildlife Management Incentives For The Private Landowner (GPAC 1989).

> "The GPAC recognizes that access fees charged by private landowners or other appropriate compensation for wildlife associated recreational access can provide effective incentives for landowners to include wildlife management as an intergral part of their total land management strategy. Since habitat quality and quantity are the critical factors limiting wildlife populations, the GPAC supports the principle of appropriate agencies providing educational and technical assistance to landowners requesting such assistance. The GPAC also supports the principle of private landowners charging access fees or obtaining appropriate compensation for wildlife associated recreational use opportunities when those fees charged or compensation received, encourages sound management practices which enhance and sustain wildlife populations".

This position statement was reviewed and adopted by the GPAC at the June 1989 Annual Meeting. It has been disseminated to GPAC Institutions and organizations.

During the past several years Extension programs have assumed in many states, a more multi-disciplinary approach in developing and delivering educational programs to landowners and encouraging more research-extension interaction. One example is the Total Ranch Management Program in Texas, whereby range, wildlife, agricultural economics and livestock researchers and specialists are coordinating their efforts to focus on managing and marketing all ranch resources to increase diversity and profitability (Richardson 1989). Other recent examples include: The First International Wildlife Ranching Symposium held in New Mexico in 1988 (Valdez and Knight 1989); the symposium on Valuing Wildlife: Economic and Social Perspectives, held in New York in 1987 (Decker and Goff 1987); the First Eastern U.S. Conference on Income Opportunities for the Private Landowner Through Management of Natural Resources and Recreational Access, held in West Virginia in 1989 (Grafton and Ferrise 1990) and; the First Symposium on Fee-Hunting On Private Lands In The South, held in South Carolina in 1989 (Yarrow 1990). Obviously, numerous other conferences and symposia have been held in recent years and will occur in the future with considerable involvement in, if not leadership by, Extension professionals.

As a further note, however, beyond the availability of conference and symposium proceedings, many useful publications and videotapes have been developed for use by professionals and by landowners. As an example, from the conference held in West Virginia in 1989, several Issue papers, other documents and a videotape have been developed and are being disseminated to researchers, Extension professionals, agencies and policy makers as well as to other interested community leaders, organizations and individuals. Some of these include: An Executive Summary of the Conference (Colyer, et. al. 1989); A Preliminary Report on Statutory Trespass/Liability Law in the Eastern United States (Alt, et. al. 1989); Research Issues Related to Recreation Enterprises For The Private Landowner (Colyer and Smith 1990); Research Issues Related to Recreational Access, (Libby 1990) and; Fish and Wildlife Habitat --Evaluating Habitat (Byford 1990). It is expected that another 26 Extension publications in the series "Natural Resources Management and Income Opportunity" will be completed and available by the end of 1990. In addition there is an ongoing effort to develop a regional research project for the Northeast in the near future.

I share these with you as examples of Extensions involvement and role in the field of recreational access. Presently, after reviewing annual reports from all the State Cooperative Extension Service it appears that there are similar programs of different levels of intensity going on in over 30 (SCES's) across the nation.

Does Extension have a role? You bet. However, a few caveats may be in order to avoid misconception or misunderstanding. These are educational programs which use available research and demonstration information as well as identify needed research. They are not advocacy programs. They do not advocate private ownership of wildlife, fee access, nor selling wildlife. They are, however, oriented toward encouraging natural resource sustainability and enhancement by helping landowners and managers understand that maintaining a strong natural resource base will be an asset to their ongoing operations and may afford new income alternatives.

Extension's vision on this issue is fairly clear, environmental degradation and a continual decline in natural resources sustainability must be reduced or stopped on private lands over the next few decades. However, to help these landowners and managers achieve this we must help them understand and implement a diversity of management practices that will enable the incentives to outweigh the disincentives.

If such efforts are successful, the benefits which should occur from conducting such programs will result in a "win-win-win" situation for the landowner, for the sportsmen/recreational user, for natural resources managing agencies and organizations, as well as for the public interest from the standpoint of helping ensure the sustainability of a strong natural resource base for future generations to use and enjoy. To make this happen, however, will require a significant amount of cooperation and coordination among agencies, organizations, institutions and policy-makers with mutual interests, and a sincere commitment of time and resources to assist and work with the private landowner and the public interests.

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A REVERSE GRAVITY SPECIFICATION FOR TRAVEL COST MODEL

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A problem frequently encountered in the estimation of recreation demand models is the availability of data. Often, the only data available (and certainly the easiest and least expensive to collect) is that gathered from users of a site, a so-called choice based sample. This is not the most desirable data from an economic point of view because it is not representative of the general population. There are several econometric methods which can be used to correct for bias created by using choice based data, but they are often difficult to estimate and use. To further compound the problem, many times the only available data are aggregate data, or data that can only be used in an aggregate form. The analyst may only know the number of visitors to a site from a set of origin zones. Alternatively, the site may be one characterized by infrequent visits so the vast majority of users make only one visit. Under such circumstances, the individual travel cost model cannot be used.

Is there a model that can be designed specifically for choice based data or aggregate data that can be used to estimate demand and net economic value? In this paper, we suggest there is, and attempt to put it into the context of a reasonable representation of the decision process. That is, we attempt to tell a story that makes the model reasonable.

The model is a "reverse gravity" model. The gravity model has been used for modelling recreation demand in several studies (e.g., Cesario and Knetsch 1976, Ewing 1980, Sutherland 1982). The standard gravity model, as applied to recreation demand, considers the individual's choice of a recreation site, weighting alternative sites in inverse proportion to the cost of visiting them. The "reverse gravity model" used here considers the likelihood that a recreation visit observed at a particular site originated in one of a number of origins. In this variation of the gravity model, trip origins are weighted in inverse proportion to the cost to the users of reaching the recreation site. The reverse gravity model was used in studies by Peterson, Anderson, and Lime (1982), Peterson, Stynes, and Arnold (1985), and by McCollum et al. (1990).

The model consists of two independent components: the trip generation component and the trip distribution component.

Trip Generation Component:

$$N_j = g(h(A_j), M_j) \qquad [1]$$

Trip Distribution Component:

$$Pr(i|j) = f(K_i, TC_{ij}, S_i) \qquad [2]$$

where

N_j = the total number of recreation trips to site j.

$h(A_j)$ = a function of site characteristics or site attractiveness.

M_j = an index of accessibility of site j to the market area from which it attracts trips.

$Pr(i|j)$ is the probability that a trip observed at site j came from origin i.

K_i is a vector of characteristics of origin i.

TC_{ij} is the cost of a round trip to site j from origin i.

S_i is a vector of the prices of substitutes for a trip to site j from origin i.

The trip generation model estimates the total number of recreation trips that will arrive at a given site. The trip distribution model estimates the relative proportions of those total trips coming from each origin within the relevant market area. The total demand for trips to site j from origin i, then, is the product of the trip generation component and the trip distribution component:

$$N_{ij} = N_j \bullet Pr(i|j) \quad , \qquad [3]$$

where N_{ij} is the number of trips from origin i to recreation site j.

Equation [3] is a trip demand function from the point of view of the site operator. It represents the number of trips the site operator can expect to appear at the gate as a function of user cost, site characteristics, and market area characteristics. The site operator can induce changes in demand by manipulating site characteristics. For example, he could increase the capacity of a campground or open a new nature trail. Those effects would enter the model through the trip generation component. The site operator can also experience exogenous (to the site) changes in the distribution of demanded trips from changes in the relationship between the site and its surrounding market area. For example, a new housing development could be built close to the site, or a new road could be built that dramatically reduced the time and expense of getting to the site. Those effects would enter the model through the trip distribution component.

In application, the model has been specified using a multinomial logit:

$$N_{ij} = g(h(A_j), M_j) \bullet \frac{\exp(f(K_i, TC_{ij}, S_i))}{\sum_{h=1}^{m} \exp(f(K_h, TC_{hj}, S_h))} \qquad [4]$$

where $(f(K_i, TC_{ij}, S_i))$ was of the form:

$$b_k \bullet \ln(K_i) + b_c \bullet \ln(TC_{ij}) + b_s \bullet \ln(S_i), \qquad [5]$$

and there are m origins that deliver trips to site j. In practice, the model has fit the data quite well, and values derived from the model have compared favorably with those estimated using other model specifications (see Hellerstein (1989) for those details).

The question we want to pose is: "Is there a context into which we can fit this model to make it a reasonable model theoretically?" What we propose is that there might be two. One considers demand as a random variable and argues that as long as one has an unbiased estimator of demand, consumer surplus measures derived from it will be unbiased estimates of the "true" consumer surplus. The second possibility considers a Poisson process as a representation of the individual decision making process aggregated over origin zones.

Demand as a Random Variable

Assume that the true demand function for a good or service is

$$Q = f(p, z) + e, \qquad [6]$$

where Q is the quantity demanded, p is the price of the good or service, z is a vector of other relevant variables, and e is an independent and identically distributed error term with an expected value equal to zero. This rather common formulation separates demand into a nonstochastic component equal to f(p, z), and a stochastic component equal to e. In the case of an individual, the nonstochastic component acts as a "permanent mean," and the stochastic component acts as a "transient shock." "True" consumer surplus can be estimated from this demand function as

$$CS = \int (f(p, z) + e)\, dp \qquad [7]$$

The expected value of consumer surplus is

$$E(CS) = E(\int_{p_0}^{p_1} f(p, z)\, dp) + E(\int e\, dp) \qquad [8]$$

$$= \int_{p_0}^{p_1} f(p, z)\, dp + E(e)(\int 1\, dp)$$

$$= \int_{p0}^{p_1} f(p, z)\, dp$$

= CS of the expected demand.

This implies that an unbiased predictor of the expectation of demand will yield an unbiased predictor of consumer surplus. This is true regardless of the underlying nature of demand. The idea is that an individual's response to price changes is completely summarized by changes in mean behavior. Therefore, expected consumer surplus is strictly a function of mean behavior.

Now consider a probabilistic view, and describe demand as a random variable. This random variable is assumed to behave according to a probability distribution, with the mean (and other moments of the distribution) functions of the parameter(s) of the distribution. For distributions like the normal or Poisson, the mean is directly equal to a "mean" parameter (μ and λ, respectively). Estimation would be used to obtain a best guess of the relevant parameter(s). The parameters can be viewed as functions of measurable factors, such as price and income.

Suppose a Poisson distribution were assumed and the parameter, λ, set equal to f(p, z). The function f(p, z) is now the statistical expectation of demand rather than a "permanent mean" as in the usual approach where demand is separated into stochastic and nonstochastic components. The random variable approach implies that a given realization of the random variable (i.e., an observed value) is not separable into permanent mean and transient shock components. Rather, the mean summarizes information describing how often realized values fall within specified intervals--the mean is an artifact of a probability distribution.

The random variable approach forces us to consider the validity of deriving measures of value from a set of estimated parameters of a probability distribution. The question becomes: Can a parameter that merely describes the distribution of a random variable convey information about underlying preferences? We argue that any random variable model that specifically corrects for non-negativity and other constraints on permissable values to reveal an unbiased prediction of the expected value of demand, conditional on prices and other relevant factors, will also yield unbiased predictions of consumer surplus.

Consider a continuous good, X, with demand equal to $x(p, z)$. Increasing p by Δp will cause X to decrease by ΔX. A rough measure of the additional expenditure needed to compensate for the increase in price is $(X - \Delta X)\Delta p$. Repeating this exercise yields a set of Δp, $(X - \Delta X)$ pairs. Integration under a demand function, or consumer surplus, is the summation of the products of these pairs as Δp approaches zero.

For a discrete commodity, D, the same process holds, except that most of the time ΔD will be 0, with occasionally $\Delta D < 0$ (i.e., $\Delta D = -1$). Observing $\Delta D = -1$ implies that the value of the marginal unit is p, since for any smaller price the consumer was better off retaining the unit.

Observing 0 is less informative, it simply says the marginal unit is worth at least p.

When demand behaves as a random variable X (or D) is indeterminate. Instead we observe realizations of a random variable. A single f(p, z) no longer exists. Instead, actual demand is drawn from a family of demand functions F(p, z). Rather than describing observed demand strictly as a random variable, we define the draw from F(p, z), $f_s(p)$, as the realization of the random variable. We have dropped the other variables from the demand function for convenience and use s as indexing a draw from S, with S being the set of all possible "states of the world."

Assume that: (1) Changing the price will not change the realization (s) of the random variable. In other words, price is independent of all other factors conditioning an individual's preferences. (2) Given s, the laws of neoclassical economics still hold. If these assumptions can be accepted, then $f_s(p)$ will behave like a standard neoclassical demand function. In particular, it will be decreasing in own price. If the state of the universe could be held constant, so that s was always the same, then $f_s(p)$ could be identified and used for consumer surplus estimation. In terms used above, a set of Δp, $(X - \Delta X)$ pairs could be generated and used to calculate consumer surplus.

The state of the universe cannot be held constant, however. Instead, each observation represents a new draw, a new realization of the random variable. Instead of absolute statements, the analyst can only hope to make probabilistic statements. In particular, the expected value of consumer surplus can be calculated as

$$E(CS) = E_s\left(\int f_s(p)\, dp\right) = \int E_s(f_s(p))\, dp \ . \qquad [9]$$

The key term is $E_s(f_s(p))$--the expected value of the demand function. The implication is that holding p constant, the observed value of demand depends on s (i.e., conditional on p, a distribution of values exists, with the observed realization dependent on s). Therefore, a cumulative distribution function on s[1] will indirectly produce a probability distribution on observed demand--ceteris paribus, demand will behave like a random variable. Furthermore, as p changes, this distribution (of demand) will also change. For example, an increase in p will shift the entire distribution downward; all realizations of s are now associated with less demand than when p was higher. Hence, one can say that the effects of the "unobservable" s is observationally equivalent to the distribution of demand being a function of p. As a result, we really do not need to derive F(p, z), the family of demand functions. All we need to discover is the "reduced form like" relationship between p and the cumulative distribution function of demand--back to the demand as a random variable idea. To reiterate, we need to find how the distribution of demand varies as p varies, where this distribution is stable given a fixed p. Stable in this context means that, with p held constant, the values of demand within any sample (in the limit) will converge to the same distribution.

In summary, the basic result is that the analyst can ignore just how the mean of the random variable is generated. The consumer surplus employing the mean of the random variable incorporates probabilities reflecting how often the marginal good is less preferable than the marginally incremented price. Additionally, despite the step-like nature of demand functions for discrete commodities, inferring consumer surplus

[1]As a state of the universe, s may be thought of as an M dimensional vector of characteristics.

measures from count and continuous models is essentially the same; it involves integrating under a predictor of the mean.

The requirement for an unbiased predictor of the mean tells us nothing about how to discover what that predictor should be.

Demand as a Poisson Process

Suppose that every day (or every weekend) an individual in an origin zone is faced with numerous options, one of which is to take a trip. The individual will choose the "take a trip" alternative only if the resulting utility is greater than what would have been obtained had any other alternative been chosen. The actual quantity of trips demanded from residents of the zone will then be the result of a number of random draws, each draw being a moment of decision. Over the entire aggregation zone the probability of an individual choosing to take a trip is very small and the number of trials is very large.

In econometric terms, this is essentially a repeated discrete choice story, with the probability of choosing to take a trip, at any given moment of decision, a function of prices, demand shifters, and a random component. Because we are unable to examine each discrete choice (i.e., we can only look at the net result of many such choices), the best we can do is indirectly model the probability of the individual making the choice. One way to model that probability is to use a Poisson count data model. The Poisson probability density function is

$$p(y) = \frac{\lambda^y}{y!} e^{-\lambda} , \qquad y = 0,1,2,... \qquad [10]$$

A Poisson process is generated by dividing an interval of time (or space) into many non-overlapping segments. Within each segment an event may occur with some small probability. If this probability is independent across segments, then the Poisson distribution (as the limit of the binomial) describes the number of occurrences of this event in the interval as each segment length becomes very small. The mean of the Poisson, λ, is simply the number of segments times probability of success in each segment.

If the Poisson parameter, λ, is specified using a fixed effects error component, i.e.

$$\lambda = f(Z, \beta; e) = \exp(Z\beta + e), \qquad [11]$$

where Z is a matrix of characteristics, β is a vector of parameters, and e is an independent and identically distributed error term with expectation equal to zero, the reverse gravity model can be derived as shown by Hausman, Hall, and Griliches (1984, p.919). Letting

$$p_{ij} = \frac{\lambda_{ij}}{\sum_j \lambda_{ij}},$$

so as to produce a share model,

$$P_{ij} = \frac{\exp(Z_{ij}\bullet\beta + e_j)}{\sum_j \exp(Z_{ij}\bullet\beta + e_j)} = \frac{\exp(Z_{ij}\bullet\beta)}{\sum_j \exp(Z_{ij}\bullet\beta)}. \qquad [12]$$

Choosing the elements of the Z matrix to correspond to the characteristics in equations [1] and [2] we get exactly the reverse gravity model.

From a statistical point of view the Poisson has some attractive features for recreation demand. First, it is a strictly non-negative distribution, thereby eliminating the problem of what to do about negative numbers of trips. Second, it is a discrete distribution, eliminating any problems of fractional trips. The Poisson does a good job at explaining the distribution when numbers of trips are clustered; for example, when there is high probability that people will take 1, 2, or 3 trips but very small probability they will take 6, 7, or 8 trips. In addition, it is relatively easy to estimate.

There are also some limitations imposed by using a Poisson distribution. One is that events occur independently over time (or space). For short periods of time, or for unique sites characterized by infrequent visits, this may not be a problem. For longer periods of time, or for sites with many repeat visits, this assumption may prove problematic. Another limitation is that the mean is equal to the variance. This may be a strong assumption and may fail to account for the overdispersion--the variance exceeds the mean--found in many data sets, as discussed by Cameron and Trivedi (1986).

These limiting assumptions can be mitigated to some extent by generalizing the model. The generalizations can include allowing for inter-person heterogeneity and/or changing the ratio of variance to mean. "Compound Poisson" models are discussed by Cameron and Trivedi (1986), whereby the Poisson model is generalized by alternative modellings of the error term in the fixed effect Poisson. Such generalizations are also discussed by Hausman, Hall, and Griliches (1984) and Gourieroux, Montfort, and Trognon (1984a,b). For example, a negative binomial distribution results from assuming the error term is distributed as a gamma random variable. This is similar to the "apparent contagion model" in the biometric literature, whereby individuals have a constant but unequal probability of experiencing an event. A different model is the "true contagion" model where all individuals initially have the same probability of experiencing an event but this is modified by prior occurence of events. Other possibilities include: the "proneness" model according to which individuals are heterogeneous in respect to their proneness to certain events, with this heterogeneity attributed to individual and/or environmental factors; or the "spells" model in which events occur in clusters and are dependent.

One cost of these generalizations, of course, is computational complexity. Whereas the Poisson can be estimated relatively easily, the negative binomial is very complex. For other assumptions about the error term, like the standard normal, the resulting compound Poisson might not have a closed form, and be very cumbersome to estimate.

Closing Remarks

The reverse gravity model was described and it was observed that, in practice, this model seems to fit the data well when used with aggregate data from choice based samples. Because empirical data are often of this form, the reverse gravity model appears to be a useful means by which to derive measures of net economic value. To date, however, the model has not been set out in any context of modelling a behavior process.

Two approaches were discussed to arriving at the reverse gravity model. The random variable approach claims that all one needs to estimate consumer surplus is an unbiased estimate of expected demand. The Poisson process approach describes observed behavior in the aggregate. In fact, the two might be related. The random variable approach abstracts from how and why the randomness arose. The Poisson or some compound Poisson process could be driving the demand and the aggregate behavior process.

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RECREATION CHOICES AND IMPLIED VALUES OF TIME

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Recreation Choices and Implied Values of Time

Two of the more fundamental unresolved issues in the literature on recreation demand are the appropriate treatment of time and how best to model the quantity choices recreationists make. The importance of the cost of time in calculating recreation-related benefits has been recognized since the earliest studies by Clawson (1959) and Knetsch (1963), and a variety of approaches (conceptual, empirical, and ad hoc) have been proposed for modelling the role of time in recreation choice and the determination of its appropriate opportunity value in deriving benefit estimates. Since the widely-cited paper by McConnell (1975) which, among other things, pointed out that the quantity measure most consistent with the travel cost method is the number of trips taken, most studies have presumed that individuals act to choose the number of recreation trips and a composite good, subject to time and money constraints. It is generally recognized that the time spent at a recreation destination may also be subject to choice and therefore be endogenous, but this choice has received comparatively little attention. Generally, analysts have dealt with this issue, if at all, by treating visits as quality-differentiated and modelling the individual's demands for trips of varying length.

This paper explores a simple model of recreation behavior where the individual chooses both the number of recreation days *and* the number of trips (or, equivalently, the average length of stay) at various recreation destinations, subject to time and money constraints. Its purposes, aside from introducing the joint quantity choices, are threefold. First, it is shown that even when an individual has fixed work weeks (i.e., does not vary hours worked at the margin), the wage rate is an appropriate measure of the scarcity value of time if work is not a source of (dis)utility and the individual uses a two-stage budgeting process to first determine the labor-leisure choice and then to allocate leisure among various alternatives. Second, the different values of time from the two-quantity model are interpreted. In addition to the scarcity value of time, travel time and onsite time both have commodity values, or values in use, that are revealed from the first order conditions for optimal choice and can be measured easily from suitable data.

Finally, and perhaps most importantly, the case where work is a source of utility or disutility, and the wage rate is no longer the relevant scarcity value of time, is considered. The motivation here is to ask whether recreationists' *actual choices* of how many trips to take and how many days to take, as optimal solutions of the two-quantity choice problem, can reveal their values of time. In its most general form, the model does not reveal scarcity or commodity values of time, since there are more unknowns than relationships among them. But perhaps a plausible restriction on preferences, like the assumption that marginal utility of hours worked is zero which has been used in most of the previous literature on this subject, can be used. One possible restriction is suggested, and its implications for measuring values of time are analyzed. The approach is illustrated by computing angler values of time using data from a salmon sport fishery.

An important feature of the two-quantity model used in this paper, as with a number of other recent recreation studies, is that consumption goods have time and money costs of *access* as well as marginal prices of consumption. One major difference is that this model presumes that what individuals gain utility from is the *time* spent in consumption of recreation and travel, so time enters the utility function as well as a constraint. This facilitates the interpretation of various first order conditions as marginal money values of time. A second major difference is the joint choice of trips and days. When the choice of days is combined with the choice of trips, which packages a given number of total days into a specific average duration, the values of travel time and onsite time in different activities are revealed by the recreationist's optimal choices. This model provides a sample-based approach to determining recreationists' values of time, like the model of McConnell and Strand (1981), but unlike their approach, the value of time is a function of parameters the individual faces and not a ratio of random variables. The model sheds some insight on comments by various authors that upward or downward biases can result from ignoring the utility of travel time. If the scarcity value of time is non-negative, and individuals are observed to take multiple trips to a recreation site within the period of analysis, according to this model they necessarily must receive *positive* marginal utility of travel.

The next section presents a brief review of some of the fundamental issues involved in measuring values of time and in modelling recreation choices. Then a simple model of recreation behavior, involving the joint choice of trips and days, is presented, and the values of time implied by optimal choices are derived. An empirical illustration of the method is provided, and the paper closes with a discussion of some limitations and possible extensions of the work.

Some Issues in Measuring Values of Time and Modelling Recreation Choices

The first analytical approach to measuring outdoor recreation demand, and still in wide use, is the travel cost method. Applied originally by Marion Clawson (1959) based on a suggestion of Harold Hotelling's (1949), the travel cost approach is an essentially empirical approach to tracing out the demand for services of a recreation site, based on the observed visits-distance relationships. It was recognized even in the earliest applications (Clawson; Knetsch, 1963) that time required to gain access to a recreation site presents a cost separate from the money cost of access, and the potential bias in benefit estimates from ignoring time was illustrated in Cesario (1976). Cesario and Knetsch (1970) suggested that travel time be combined with travel cost in a single variable, to avoid estimation problems due to the high collinearity of time and money costs. Cesario suggested that an appropriate value for travel time is one-quarter to one-third the wage rate, based on results from the transportation literature.

A major advance was made by McConnell and Strand who, using a maximizing framework that included the labor-leisure choice, showed that an estimate of the value of travel time can be derived from the ratio of estimated coefficients on travel cost and the product of travel time and the wage rate. The advantage of their approach is that the value of time is a sample-determined fraction of the wage rate, instead of being chosen arbitrarily by the analyst; a disadvantage is that their approach values time spent onsite at zero. Bockstael, Strand, and Hanemann made a further advance by a more thorough analysis of the individual's labor market situation, showing that the marginal wage rate serves as the appropriate opportunity cost of time for individuals who work flexible hours and can trade time for money at the margin. They argued that for individuals with fixed work weeks the wage rate (or some fraction thereof) is not a suitable measure for the value of time. They showed the implications for demand specification of these two kinds of labor market situations, and illustrated how utility-theoretic parameter estimates and welfare measures can be obtained from maximum likelihood estimation.

Somewhat less attention has been given to the question of the quantity choices recreationists make. The travel cost method began as an essentially empirical method, and in early studies the quantity variable was sometimes specified as trips taken and sometimes as total days. McConnell provided the first formal utility-theoretic framework for recreation choice[1], and showed that the most consistent measure of recreation quantity in the travel cost approach is trips, not days. He also noted that the marginal cost of a user day is independent of the travel costs, and the demand for user days should be a function of net variable cost per day including time cost. Thus, the total time spent on a recreation trip is costly, not just the time spent in transit.

Wilman (1980) attempted to distinguish between values of travel and onsite time in a model where individuals choose the number of round trips and visits of different fixed lengths. Smith, Desvouges, and McGivney (1983) showed that the distinction in her model was arbitrary, and proposed instead a model based on the household production approach where individuals choose both the number of visits and time spent onsite at various recreation sites. They showed that in general the opportunity cost of travel time will differ from the wage rate, but because they did not have a means of determining this time cost, they were not able to implement their model empirically.

A Model of Recreation Choices

The model developed and motivated in this section has a structure similar to the model used by Bockstael, Strand and Hanemann, and the two-quantity choice was also proposed by Smith, Desvousges, and McGivney. The choice framework is simple and necessarily abstracts from certain elements of real world choice, but captures the essential additional information about valuation of time that is revealed by an individual's choices of days in addition to trips.

Consider a person who is unable to vary hours worked at the margin.[2] The individual is presumed to allocate his or her non-work time t and income m between a set of recreation activities $d_1,...,d_n$, and a non-recreation leisure activity z, all measured in time units and having parametric money prices per unit time of $\delta_1,..,\delta_n$, and p, respectively. In order to consume d_j, costly travel to site j is required. The travel has a fixed time requirement α_j, and a fixed money cost γ_j (for j=1,...,n); also, travel is a source of utility or disutility, and the individual chooses the number of trips r_j to site j. Since trips have a fixed time requirement, choosing the number of trips to a site is equivalent to choosing the amount of travel time to site j. The individual is presumed to choose d_j and r_j, j=1,...,n and z to maximize to maximize the quasiconcave utility function U(d,r,z), where $d = (d_1,...,d_n)$ and $r = (r_1,...,r_n)$, subject to the constraints that the time spent equals t and the money spent not exceed m. The time prices of consumption for d_j and z are identically 1 (a unit of consumption of time takes a unit of time), whereas the time price of a trip to site j is α_j.

While the access and consumption prices are assumed fixed for each individual, they will generally vary between individuals because of differences in distance to sites, differences in transportation vehicles or modes, and differences in capital stock devoted to recreation activities. For example, the money cost of travel per mile will differ markedly between recreationists who travel on motorcycles and those who travel in motorhomes. Likewise, the decision to take a hotel on longer trips may be different for travellers with cars than for travellers with motorhomes, and for tent-owners compared with those who don't own tents. Similar considerations motivate the expectation that there will be differences in money prices of consumption onsite. The decisions that result in these differences in time and money parameters between individuals are taken to be exogenous to the marginal, or short-run, decisions of how to allocate time and money over the course of a season, or a portion of a season.

It is important to note that when individuals choose both the number of total days of recreation at a site and the number of trips to the site, they implicitly choose the average duration of their activities; that is, one can write

(1) $$d_j \equiv r_j \cdot s_j,$$

where d_j is the individual's total days for recreation activity j, r_j is the number of trips taken by for j, and s_j is the average onsite time or length of stay for activity j. The recreationist makes two quantity decisions for each activity, with the third determined implicitly by the identity (1).

The money constraint is

(2) $$m \geq pL + \delta d + \gamma r$$

where p and $\delta = (\delta_1,..,\delta_n)$ are the parametric money prices per unit time of z and d, respectively, and $\gamma = (\gamma_1,..,\gamma_n)$ is the fixed money cost of access to d per trip. While the index for individuals is suppressed to keep notation simple, it is important to note that all terms in (2)-- choice variables and parameters-- vary over individuals.

The time constraint is

(3) $$t \equiv z + ed + \alpha r$$

where $e = (1,...,1)$ is the unit n-vector and $\alpha = (\alpha_1,..,\alpha_n)$ is the fixed time cost of access (i.e., the travel time) to d_j per trip. Note that (3) holds as an identity, as all time is spent in some activity, even if it is "doing nothing."

The lagrangean for the optimization problem is given by

(4) $$\pounds = U(d,r,z) + \lambda(m - \delta d - \gamma r - pz) + \mu(t - ed + \alpha r - z)$$

and is maximized by choice of $d_1,...,d_n$, $r_1,...,r_n$, and z. The first order conditions for an individual to choose to consume recreation at a site j (i.e., for an interior solution) are

(5) $$\pounds_{d_j} = U_{d_j} - \lambda\delta_j - \mu = 0, \qquad j=1,...,n$$

and

(6) $$\pounds_{r_j} = U_{r_j} - \lambda\gamma_j - \mu\alpha_j = 0, \qquad j=1,...,n$$

in addition to the first order condition for choice of optimal (interior) choice of z,

(7) $$\pounds_z = U_z - \lambda p - \mu = 0$$

and the constraints. It is assumed that the money constraint binds, so the marginal utility of money is strictly positive; the time constraint holds as an identity, so the marginal utility of time can have any sign.

Equations (5)-(7) can be rearranged slightly to give familiar[3] expressions for the commodity values of time in its various uses:

(8) $$U_{d_j}/\lambda = \delta_j + \mu/\lambda$$

(9) $$U_{r_j}/\lambda = \gamma_j + \alpha_j\mu/\lambda$$

and

(10) $$U_z/\lambda = p + \mu/\lambda.$$

Each of the left-hand expressions in (8)-(10) is (in DeSerpa's terminology, which appears to be widely used[4]) the marginal commodity value of time in its various uses (recreating at site j, travelling to site j, or engaging in other leisure), while μ/λ is the scarcity value of time. Intuitively, since μ is the marginal utility of (another unit of) scarce time, and is the marginal utility of income, the ratio μ/λ is the marginal money value (i.e., opportunity cost) of a unit of time used optimally. however, each of the uses to which time can be put in this model also has a direct money cost or price. For instance, since it costs δ_j dollars per unit of time (e.g., a day) to consume d_j, the full cost at the margin of spending a unit of time doing d_j is $\delta_j + \mu/\lambda$, and at the optimum this must just equal the value received from that unit of time, U_{d_j}/λ. Thus, while the scarcity value of time is μ/λ, the value of time spent in d_j is $\delta_j + \mu/\lambda$. Similar interpretations apply for the marginal values of time spent in other leisure (z).[5]

As for travel time, each additional trip to site j involves α_j units of travel time which generate (dis)utility, and the value of the trip (travel only) at the margin is $\gamma_j + \alpha_j(\mu/\lambda)$, from (9). Thus, the *average* value of travel time is $\gamma_j/\alpha_j + \mu/\lambda$. Again, this makes sense intuitively, since the average money cost per trip is γ_j and averaged over the α_j units of travel time required for the trip the money cost of travel time is γ_j/α_j. Add to this the scarcity value (opportunity cost) of the time spent in travelling, and the full cost of travel time is $\gamma_j/\alpha_j + \mu/\lambda$. In equilibrium the optimal number of trips chosen is such that the value of time spent in travelling (i.e., its commodity value) must just equal this cost.

A common assumption in previous studies is that the marginal utility of travel time is zero, and some authors (e.g., Cesario) have been concerned about possible biases if travel time yields utility or disutility. The present model, by separating the choices of trips and days, allows for non-zero value of travel time. It is interesting to note in passing that if the scarcity value of time (μ/λ) is nonnegative, and recreationists are choosing multiple trips, this model shows [via (9)] that the marginal utility of travel time must be strictly positive. According to this analysis, then, there is a potential bias from assuming the marginal utility of travel time is zero, and it is unambiguously a downward bias when the scarcity value of time is nonnegative.

In analyzing values of time, it is important to note the distinction between commodity and scarcity values of time. In travel cost demand models both the time spent travelling and the money cost of travel are parameters which enter the demand function. Because they are usually highly correlated statistical estimation of their separate effects is often difficult. This has motivated the search for monetary values of time which can be used to combine travel time and travel cost into a single variable. But which value of time should be used? The commodity values specify the monetary worth of time in particular uses. This combines the scarcity value of time, the money equivalent value of generally scarce time, with a purely monetary cost which must also be paid in that use of time. At the margin, with the ability to freely adjust travel time through the choice of trips, the value of time spent in a particular use such as travel is the commodity value, $\delta_j + \mu/\lambda$. However, this value of a use of time has already incorporated the tradeoff between time and money, which is the scarcity value μ/λ. Thus the researcher seeking a value to use to collapse time and money parameters into combined variables should seek to use the scarcity value of time, whereas those interested in the value of travel time should seek the commodity value[6].

With this model, as with most neoclassical choice models, the potential appeal of conditions such as (8)-(10) is that one can infer marginal valuations of commodities (or, as here, uses of time) from observed costs that consumers face. This would be possible *if* the scarcity value of time were known. A number of papers, beginning with McConnell (1975)[7], have incorporated a labor-leisure choice into the model, with utility unaffected by the number of hours worked; one of the conditions of those models is that the scarcity value of time must equal the marginal wage rate.[8] In such cases, all of the full costs of recreation and travel time would, in principle, be observable and by (8)-(10), the values of time in various uses could be determined for each individual by the wage rate and parameters he or she faced. However, as Bockstael, Strand, and Hanemann argue, the line of reasoning that permits one to conclude the scarcity value of time is the wage rate breaks down when, in fact, individuals cannot vary hours worked at the margin.

One of the purposes of this paper is to show that even for people who cannot vary hours worked at the margin, the wage rate is the scarcity value of time if work does not affect utility and individuals make their choices by two-stage budgeting: initially choosing the optimal hours worked and hours of leisure (thereby implicitly choosing income), using an aggregate quantity index of leisure activities; then (perhaps at a later time) choosing the specific optimal mix of leisure activities via a problem such as the one described in (4)[9].

To further develop the idea of two-stage budgeting for this problem, consider that the consumer has a utility function $u(h,g(\mathbf{d},\mathbf{r},z))$, where h is hours worked, $\mathbf{d} = (d_1,...,d_n)$, and $\mathbf{r} =$

$(r_1,\ldots,r_n)$. Weak separability of u, as written, is necessary and sufficient for problem (4) to be the second stage of two-stage budgeting for the leisure group in this problem (see, e.g., Deaton and Muellbauer, pp. 123-4). The second stage has indirect utility and expenditure functions derived in the usual way, viz., $e(\delta,\gamma,\alpha,p,t,v) \equiv \{\min \delta d + \alpha r + pz: v=u(d,r,z),\ t = ed + \alpha r + z\}$. Its inverse with respect to m is $v(\delta,\gamma,\alpha,p,t,m) \equiv \{\max U(d,r,z): m - \delta d - \gamma r - pz = 0,\ t - ed - \alpha r - z = 0\}$, or the indirect utility function from problem (4).[10]

The first stage of the budgeting process can be set up as

$$\max_{h,t}\ u(h,v(\delta,\gamma,\alpha,p,t,m)) + \psi[E + wh - e(\delta,\gamma,\alpha,p,t,v)] + \phi[F - h - t] \tag{11}$$

where h is hours worked, F is total time available, E is nonwage income, and w is the marginal or discretionary wage rate, and u is increasing in both arguments. The idea here is that t and m, which are parameters in the second stage, are subject to choice in the first stage. The individual makes a determination of how many hours to work based on what is essentially a standard labor-leisure problem, trading off utility derived from work and leisure and income from work against the cost of leisure. Leisure time, t, is chosen directly, while income, m, is chosen indirectly since $m \equiv E + w(F - t)$.

The optimality conditions for this first stage problem (again, assuming an interior solution) are

$$u_h + \psi w - \phi = 0 \tag{12}$$

$$u_v[v_t + v_m(-w)] - \psi e_t - \phi = 0. \tag{13}$$

The term in brackets in (13) arises because the choice of t also determines m, as noted above.

Two cases will be considered. First, suppose that $U_h = 0$; hours worked does not directly affect the level of utility. This is a common assumption and lies at the heart of previous papers that have shown the scarcity value of time is the wage rate (see, e.g., McConnell, 1975; McConnell and Strand; Smith, Desvousges, and McGivney; and Bockstael, Strand, and Hanemann). For this case, (12) gives the expected result that $\phi/\psi = w$; the wage rate is the ratio of the first stage lagrange multipliers on time and money, respectively. The interest, of course, centers on the ratio of multipliers from the second stage, since that is the scarcity value of time that appears in (8)-(10).

To help relate μ/λ to ϕ/ψ, (13) can be simplified by noting that from the envelope theorem applied to the indirect utility function implied by (4), $v_N = \mu$ and $v_m = \lambda$. Also, it is shown in the Appendix that $e_N = -\mu/\lambda$. Using these in (13) gives

$$u_V(\mu - \lambda w) + \psi\mu/\lambda - \phi = 0.$$

With some further rearrangement, using $\phi/\psi = w$, the following expression emerges:

$$(u_V\lambda/\psi + 1)(\mu/\lambda - w) = 0. \qquad (14)$$

The left hand term is always strictly positive, since $u_V > 0$ and both income constraints are assumed to bind, meaning $\psi > 0$ and $\lambda > 0$. Thus, for (14) to hold it must be that $\mu/\lambda = w$; given an interior solution to the two-stage budget process the scarcity value of time for each stage must be equal. This result considerably extends the set of individuals for whom it is appropriate to use the marginal wage as the relevant scarcity value of time. Even if the time and money available to be allocated among various leisure activities are fixed (i.e., predetermined), the wage is the appropriate scarcity value of time if the utility function and is separable in hours worked and leisure activities and hours worked does not affect the level of utility.

Attention is turned now to the case where the restriction on preferences that $U_h = 0$ is not imposed. Johnson and Cesario, among others, have argued that $U_h < 0$. It is also not hard to imagine that for some people who really like what they do for a living, $U_h > 0$ (e.g., Chiswick). If it is true that $U_h \neq 0$, all of the approaches that equate the scarcity value of time to the wage rate break down, because as can be seen from (12), $\phi/\psi = w + U_h$, and the scarcity value of time is no longer observable as a parameter the individual faces. In situations such as these, the model of behavior is that given by it is worthwhile to ask whether there is some other structure (instead of $U_h = 0$) that can be imposed on preferences which is reasonable and, when imposed, makes it possible to determine the scarcity value of time from observed behavior or parameters individuals face.

One such restriction concerns the response of utility to changes in the average length of stay (s_j) at recreation sites. The model as formulated says that recreationists value (i.e., have utility defined over) recreation days at a site and travel to a site. Average length of stay, *per se*, does not affect utility. It does, of course, vary with changes in days or trips that do affect the utility level. However, the individual is presumed to be indifferent to "pure" changes in length of stay, or the ratio of days to trips. The mix of trips, which generate utility, and days, which also generate utility, is therefore optimal, so that changes in $s_j = d_j/r_j$ do not affect utility. This, it will be seen, is an assumption that for some j, r_j and d_j are homothetically separable in $u(\cdot)$.

This can be imposed explicitly on the model by setting $du/ds_j \equiv 0$ for some (or all) j; i.e., at the optimum with respect to d and r, the utility function will also be optimized with respect to length of stay, and no changes in s at the margin will affect utility. Formally, taking note of (1), one can write

$$du = u_{d_j}(\partial d_j/\partial s_j)|_{r_j}\, ds_j + u_{r_j}(\partial r_j/\partial s_j)|_{d_j}\, ds_j$$

$$= u_{d_j} r_j ds_j + u_{r_j}(-d_j/s_j^2)ds_j$$

$$= r_j(u_{d_j} - u_{r_j}/s_j)ds_j.$$

Thus, to impose $du/ds_j = 0$, one must have $u_{d_j} = u_{r_j}/s_j$ or, since $s_j \equiv d_j/r_j$, $d_j u_{d_j} = r_j u_{r_j}$. The implication of this restriction is that

(15) $$\frac{u_{d_j}}{u_{r_j}} = \frac{r_j}{d_j}.$$

Thus the utility function is homothetically separable in the arguments r_j and d_j; increasing them by any arbitrary factor θ leaves the marginal rate of substitution between trips and days to j unchanged.[11] Using (15) with the first order conditions (5) and (6) means that

$$\frac{u_{d_j}}{u_{r_j}} = \frac{\lambda\delta_j + \mu}{\lambda\gamma_j + \mu\alpha_j} = \frac{r_j}{d_j}$$

which solves for

(16) $$\mu/\lambda = \frac{\gamma_j r_j - \delta_j d_j}{d_j - \alpha_j r_j} = \frac{\gamma_j - \delta_j s_j}{s_j - \alpha_j},$$

which is in principle observable from the prices an individual faces and the optimal choices he or she makes in response to those choices.

Equation (16) provides a basis for determining the values of time implicit in recreationists' choices of trips and days in response to time and money constraints and the marginal prices they face, provided the restriction (15) that changes in average length of stay do not affect utility is valid. Possibilities for testing this restriction will be discussed briefly below. To interpret (16), the implied value of time is the difference between total money costs of taking trips and the total money costs while at the site (numerator), divided by the difference in total time spent at the site and in travelling. One virtue of (16) is that it allows for sample-based calculations of the value of time. In general the value of time will vary over individuals (the individual index i has been suppressed), since both prices and optimal quantities vary across the sample. Note too that since the calculation is based on actual prices and quantities, its moments are more easily calculated than moments of the McConnell-Strand sample estimate of the value of time, which is a ratio of random variables (regression coefficients). It also can vary in extremely general ways across the sample with respect to respondent characteristics, whereas the McConnell-Strand approach pegged the value of time at a sample-determined fraction of the wage rate.

The price paid for these virtues is the homothetic separability restriction on r_j and d_j. One implication, at first blush, appears to be that the value of time must be *independent* of money income, which is the usual consequence of homotheticity in the standard consumer model. This is a testable implication, of course; one could calculate the values of time implied by the restriction (15), and then test whether the implied values of time have any relationship with money income. The expression in (16) for μ/λ arises from the assumption (15), which implies homothetic separability. If prices (δ_j,α_j, and γ_j) are independent of income, then with homothetically separable preferences μ/λ would not vary with money income since s_j ($\equiv d_j/r_j$) is independent of income. If preferences are *not* homothetically separable, the ratio of days to trips can vary with money income, and the value of time will vary with money income. Therefore, if one knows the prices, trips, and days taken by a recreationist, the calculation on the right side of (16) can be made and examined for variations with money income. If the calculated value of time is found to vary with income across the sample, this is evidence that preferences are *not* homothetically separable, and that the restriction (15) is rejected by the sample data.

Before this test of homothetic separability can be made, however, a special feature of this choice problem must be accounted for. One characteristic of the recreation problem, unlike the standard consumer choice problem, is that *prices may depend on income*; prices of access vary over individuals based on distance, and to a degree individuals can also influence their prices of accessing and consuming recreation based on their money income level. For example, as noted earlier, the vehicle used to travel can affect the marginal time and money costs of travel and while at the recreation site. Some recreationists use motorhomes, and others use compact cars; the choice of transport mode is probably highly dependent on money income. Since motorhomes often are driven more slowly than cars, and get lower gas mileage, α_j and γ_j would be higher, *ceteris paribus*, for motorhome owners than for car owners; likewise δ_j could be lower because motorhomes offer sleeping accomodations and reduce the need for paid lodging. Thus, while prices are taken to be exogenous for an individual (since money income is exogenous), they may depend on money income; from (16), if δ_j, α_j, and γ_j are functions of money income, μ/λ will also depend on income even though preferences are homothetically separable. Thus, to use a test of whether the implied μ/λ varies with income as a test of the plausibility of homothetically separable preferences, it is necessary first to reject the hypothesis that prices vary with income in the sample.

An Application of the Approach-- Implied Values of Time for Alaska Pink Salmon Anglers

This section provides an illustration of the ideas for measuring values of time developed in this paper.

The data used for the application are from a travel cost mail survey of pink salmon anglers who fished at Willow Creek, Alaska, in the summer of 1980. Anglers were asked to give their names as part of a Fish and Game creel census, and were later chosen randomly to receive either a travel cost-oriented questionnaire, or a contingent valuation questionnaire (each with two followups). The focus of both questionnaires was household activities with respect to salmon fishing at Willow Creek. The travel cost questionnaire had a response rate of 73% of deliverable questionnaires, and collected detailed information, for specific trips and for the season, on fishing success, prices of substitutes, and money and time spent in travel and onsite. Additional information for the season was collected on trips to Willow Creek and other salmon fishing trips, income, hours worked, and gear investment. A total of 261 observations, out of 324 returned questionnaires, had non-missing values of variables of interest and were used in the analysis.

Willow Creek is located approximately 70 miles north of Anchorage and 280 miles south of Fairbanks. The pink salmon fishery is predominantly a day fishery which receives heavy use during the summer weeks when pink salmon are in the river. Of the 261 anglers represented by the sample, roughly 75 percent indicated that their average length of stay at Willow Creek was less than 24 hours, 85 percent stayed less than 48 hours at the site, and 95 percent stayed 72 hours or less.

Table 1 provides some descriptive information about sample moments of the key variables used in the illustration. All variables are expressed on a per person basis. They are:

Prtrps- The number of trips taken by the respondent and household members to Willow Creek during the 1980 pink salmon season;

Avtim- The average length of stay on trips to Willow Creek, in hours;

Avgrp- The average group size for household trips to Willow Creek;

Gamma- The average money cost of travel *per person* to Willow Creek;

Delta- The average daily onsite cost *per person* while at Willow Creek;

Alpha- The average travel time from point of origin to Willow Creek.

From Table 1, it can be seen that the mean number of hours at the site was about 22; the average party size was slightly less than 3; money costs of travel to Willow Creek (round trip mileage at $.16/mile plus food and any lodging enroute) averaged just under $20 per person per trip; daily onsite money costs were very nominal, averaging just a little more than $1 per person per day; and round trip travel time to Willow Creek averaged slightly more than three hours per trip. There are no services to speak of at Willow Creek, apart from a restaurant/gas station nearby, which explains the small daily expenditures while at the site. No attempt was made to net out expenditures on food that would have occurred anyway. Household income of respondents averaged about $33,000/year. The mean implied value of time, using (16), was about $2.86 per hour.

Table 1. Descriptive Statistics from the Sample of Anglers

Based on 261 observations.

Variable	Mean	Std. Dev.	Minimum	Maximum	Cases
Prtrps (number)	3.2278	2.5332	.0000	15.00	259
Avtim (hours/trip)	22.425	49.651	1.000	576.0	261
Avgrp (Number)	2.7854	1.4650	1.000	10.00	261
Gamma($/trip)	19.637	47.949	.0000	711.0	261
Delta ($/day)	1.0947	2.8251	.0000	25.00	261
Alpha (hours/trip)	3.3218	3.8023	.0000	45.00	261
Valtim ($/hour)	2.8577	14.102	-34.00	193.5	240
Hinc (x10^{-3}$)	33.381	40.550	2.500	550.0	247

Table 2 presents more detail on the distribution of implied values of time in the sample. The histogram gives absolute and cumulative frequencies of values of time, in dollars per hour, implied by (16). For 21 observations, the travel time was equal to the time onsite, so the implied value of time could not be calculated since the denominator of (16) was zero; the remaining 240 observations are displayed in Table 2. Several features of the histogram are interesting. First, a plurality (41%) of the values were extremely close to zero-- between -$1/hr and $1 per hour. A total of 31%, or 74, of the implied values of time were negative, but this includes 20% (48) which fell between -$1/hour and zero. Twenty one percent of the implied values were between zero and $1/hr, another 26% were between $1/hr and $5/hr, and about 22% were above $5/hour. With the sample variance reported in Table 1 (14.1), it is clear that the mean value of time of $2.86/hour is not significantly different from zero.

Table 2. Some Details on the Distribution of Implied Values of Time for Willow Creek Anglers (Values of Time are in Dollars per Hour.)

Lower limit	Upper limit	Frequency	Cumulative Frequency
-∞	-20	2 (.0083)	2 (.0083)
-20	-10	8 (.0333)	10 (.0417)
-10	-5	5 (.0208)	15 (.0625)
-5	-1	11 (.0458)	26 (.1083)
-1	0	48 (.2000)	74 (.3083)
0	1	51 (.2125)	125 (.5208)
1	5	63 (.2625)	188 (.7833)
5	10	29 (.1208)	217 (.9042)
10	20	15 (.0625)	232 (.9667)
20	∞	8 (.0333)	240 (1.0000)

It is important not to attach too much importance to the numbers that come out of this particular analysis, since the data set was not designed for the specific calculations that are being made here, but the approach may be of more general interest. In particular, it was noted earlier that the homothetic separability restriction that underlies (16) is testable in principle. Homothetic separability would normally be manifest in linear Engel curves, which would in this model imply that the value of time is independent of income. It was pointed out, though, that it is quite plausible that prices may vary with income in a recreation choice model. Thus, before testing for dependence of the implied values of time on money income, as a possible means of rejecting the homothetic separability assumption, it must be determined that prices are independent of income.

Table 3 presents the results of some simple regression-based tests of whether the various money and time prices (δ, α, and γ) or average length of stay depend on money income. The models explained each of these as a quadratic function of income, and likelihood ratio tests were performed for the joint hypothesis that the linear and squared terms in the model were zero. It is clear from each of these tests that the null hypothesis of indepependence from income cannot be rejected. This means that the prices in (16) can be treated as independent of income, and that a test of whether the value of time is independent of money income is also a test of homothetic separability. The results of this test are also reported at the bottom of Table 3; the hypothesis of independence of implied values of time from income cannot be rejected, so the homothetic separability which is implicit in the restriction (15) is not rejected by the sample.

Table 3. Results of Chi-Squared Tests of Independence of Prices and Average Length of Stay from Income

Variable	χ^2 Statistic
Avtim	.337275
Gamma	.008004
Alpha	.447954
Delta	.136423
Valtim	.063913

Critical $\chi^2_{2,.05} = 5.99$

Some Concluding Remarks

This paper has presented a model of behavior which ties together two strands of analysis in the recreation demand literature- the joint choice of trips and days, and the valuation of time spent in recreational activities. The model was developed first for choices subject to fixed time and money constraints. It was shown that the inclusion of both quantity choices in the recreationist's decision problem leads to intuitive first order conditions for the choice of both days and trips, and the optimizing recreationalist will act to equate values of time in different activities to observable costs. The model was then broadened to include a labor-leisure choice, with two-stage budgeting. If the marginal utility of time spent working is zero, and an individual acts first to choose hours worked and leisure, then allocates fixed leisure time among competing activities, the wage rate is the appropriate measure of the scarcity value of time even though hours worked are fixed in the second stage. Next the analysis considers what happens when one drops the common, but often objected to, assumption that the marginal utility of work time is zero. In this case the wage rate no longer functions as the appropriate scarcity value of time, and other plausible restrictions on preferences must be considered. One such assumption chosen for evaluation is that average onsite time (the ratio of days to trips) does not affect utility from travel or time at the recreation site. This assumption is restrictive, as it implies that days and trips to a recreation site are homothetically separable in preferences. However, the restriction can be tested, and its virtue is that the (presumably optimal) choices by recreationists of trips and total days to spend at a site or sites reveal the values of time directly. Thus, implied values of time can be calculated directly from observed prices and quantities in the sample data. The approach is applied to a sample of recreationists from a pink salmon fishery at Willow Creek, Alaska, and it is found that the average value of time is about $2.86/hour, but is not significantly different from zero. The homothetic separability restriction that underlies this implied value of time could not be rejected by the sample data.

The specific empirical estimates of the implied value of time should be taken as illustrative, as the data set used was not designed for this particular approach to revealing values of time. The two quantity model of recreation decisions and the general approach to identifying "revealed" values of time, especially with the possibility of empirically testing the validity of key assumptions, may be of broader interest. The theoretical model suggests that in designing survey instruments, it is important to obtain estimates of the marginal daily costs as well as marginal trip costs for each site a recreationist visits. Areas for further work include estimation of the joint quantity choice model with appropriate cross-equation restrictions and exploration of other, less restrictive assumptions about the structure of preferences from which optimal choices can reveal the implicit values of time in different uses.

Appendix

Here it is shown that in equation (13), $e_t = -\mu/\lambda$. Write the expenditure function as $e(\delta,\gamma,\alpha,p,t,v) \equiv \delta d + \gamma r + pz + \epsilon[v - u(d,r,z)] + \sigma[t - ed - \alpha r - z]$. Then from the envelope theorem, $e_t = \sigma$. however, it is possible to relate the multipliers ϵ and σ to μ and λ from the dual problem (4), by examining the respective first order conditions with respect to any choice variables. The conditions for expenditure minimization with respect to d_j, for example, is

(A1) $$\delta_j - \epsilon u_{d_j} - \sigma = 0$$

whereas the condition for optimal choice of d_j from the primal problem is given in (5). It is clear from (A1) and (5) that

$$\sigma = \delta_j(1 - \epsilon\lambda) - \mu\epsilon.$$

however, for some other recreation activity d_i that is chosen, by similar reasoning it must also be true that

(A3) $$\sigma = \delta_j(1 - \epsilon\lambda) - \mu\epsilon.$$

Combining (A2) and (A3), since in general $\delta_i \neq \delta_j$, it must be true that $\epsilon = 1/\lambda$ and $\sigma = -\mu\epsilon = -\mu/\lambda$; hence $e_t = \sigma = -\mu/\lambda$.

Footnotes

1. Johnson and DeSerpa both analyzed the value of time in somewhat more general models of time allocation and labor-leisure choice, respectively.

2. This is one of the two basic cases analyzed by Bockstael, Strand, and Hanemann. They showed that for the other case, when the individual can vary hours worked at the margin, the appropriate scarcity value of time is the marginal wage rate.

3. Very similar kinds of expressions for the equilibrium values of time can be found in Johnson, DeSerpa, McConnell (1977), and Cesario.

4. Recent examples where this use of terminology occurs are Wilman, Cesario, and Smith, Desvousges, and McGivney).

5. Note that this marginal analysis abstracts from the discreteness of trips; in reality, if the optimal T_j was not an integer, the choice of T_j would be based on a comparison of utility values for the nearest integer values of T_j.

6. It should be pointed out that the value of time is observable if the model is given some structure or restricted in some way. DeSerpa argued that commodity values of time are empirically meaningless, because they can never be observed, and that focus should be placed on the "value of saving time", or the difference between the commodity value of time in a particular use and the scarcity value of time. DeSerpa's argument is correct for the completely unrestricted model. However, many models incorporate restrictions; a common one is to incorporate a labor-leisure choice where hours worked do not affect utility.

7. Other papers that have incorporated the labor-leisure choice, with work utility-neutral, are McConnell and Strand; Smith, Desvousges, and McGivney; and Bockstael, Strand, and Hanemann.

8. This conclusion is crucially dependent on the assumption that work does not generate utility or disutility, as Johnson has shown. Both Johnson and Cesario have illustrated the effect on the first order conditions of the model when hours worked affects the level of utility.

9. It is worthwhile to note that the only condition required for two stage budgeting in this problem is weak separability of hours worked from the set of leisure activities. This is considerably less restrictive than most problems to which two-stage budgeting is applied, because in this problem all the individual prices are known and there is no need to create price indexes for subgroups.

10. For a nice discussion of the two dual problems and properties of expenditure and indirect utility functions for the two constraint problem, see Smith (1986).

11. In addition, the restriction (15) implies the utility function is of the form $U(f(r_j \cdot d_j),z)$, as pointed out by Michael Hanemann.

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MEASURING RECREATION VALUES WITH MULTIPLE DESTINATION TRIPS

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Robert Mendelsohn, John Hof, George Peterson and Reed Johnson

Abstract

Traditional travel cost analyses have either ignored multiple destination trips or have arbitrarily allocated trip costs across visited sites. In this paper, we treat each multiple destination trip combination as a unique good (site) and incorporate them into a demand system. In an empirical example from Southwest National Parks, we show that the demand functions for multiple destination trips are well behaved and that they reflect almost half of the value of these sites.

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I. INTRODUCTION

Although many outdoor recreation trips have a single primary destination, it is not infrequent to find especially long and expensive trips involving multiple destinations. For example, a typical international vacation involves visits to multiple cities and natural wonders. Further, trips to exceptional but remote parks such as Yellowstone or Grand Canyon often involve stops at other regional attractions. In all these cases, both single destination and multiple destination trips are observed. However, it is not clear how the multiple destination trips should be modeled.

One approach is to try to assign fractions of total travel costs to each destination. For example, Haspel and Johnson [1982] divide total trip costs across the multiple destinations of visitors. Dividing the fixed costs of a trip amongst variable inputs, however, is invariably arbitrary. There is no way to know what fraction of fixed costs to assign to each visited site. An alternative is to calculate the marginal cost of each additional destination given a trip to another site. Using these costs, one could estimate the conditional demand function to add, for example, site j to a given trip. This conditional demand function for site j is conditional on visiting the other sites (not site j) and cannot be added to an unconditional (traditional) demand function for site j. This marginal approach also has trouble modeling whether the entire trip will be taken at all.

Most of the travel cost literature, however, either ignores whether a trip is a multiple destination trip or omits multiple destination trips altogether. Many studies simply do not ask whether the destination was the primary purpose of the trip. Those studies which do ask usually drop multiple destination visits. Both approaches are problematic because they bias the demand functions for both single and multiple destination trips.

In this paper, we develop an alternative method for analyzing multiple destination trips. Rather than allocating total travel costs across sites, we treat each combination of sites as an additional site. Each combination is represented by a demand function in a system of demand equations. By including the prices of all alternatives in each of the demand functions, the consumer's desire to substitute across single and combined site trips can be measured. The approach therefore captures the substitution consumers are willing to make between visits to packages of sites and individual sites and leads to measures of total valuation.

For example, suppose the user could visit Yellowstone, Glacier, or Yellowstone and Glacier. These three choices could be modeled in terms of a demand function for Yellowstone and a demand function for Glacier with joint trips somehow being divided between them. This division, however, is difficult to perform because it is not clear whether one site is primary or how total travel costs should be divided between them. In this model, we treat joint trips to Yellowstone and Glacier as though they were to a third site. A third demand function for visits to both sites is estimated using the total travel cost of this joint visit as a price.

In Section II, the theoretical basis for the multiple site travel cost demand model is formally derived. In order to demonstrate its empirical importance, we provide an example in Section III using data from Bryce Canyon visitors. The results indicate that treating multiple destination trips as unique, with their own demand function, yields important and consistent results. The consumer surplus emanating from multiple destination trips is large, almost equalling the consumer surplus under the single destination trip demand function. Policy implications and limitations of the technique are discussed in the concluding section.

II. MODEL

We assume that individuals have a well-behaved utility function for visits Q_1 to Q_n to sites 1 through n as well as all other commodities of X. We also assume that consumers know how to rank and value visits which combine more than one of these n sites in a single trip. Thus, their utility function is composed of visits Q_1 to Q_n as well as visits to all possible combinations of those n sites Q_{n+1} to Q_m:

$$(1) \quad U = U(Q_1, Q_2, \ldots, Q_n, Q_{n+1}, \ldots, Q_m, X, W).$$

The utility function also includes a vector of demand shift variables W.

The individual is presumed to maximize his utility function given a budget constraint which incorporates the (1 x m) vector of prices. Assuming that the utility function is well behaved, this constrained maximization leads to a system of m inverse demand equations for the m sites:

$$(2) \quad \begin{aligned} P_1 &= G_1(Q_1, Q_2, \ldots, Q_m, P_Z, W) \\ P_2 &= G_2(Q_1, Q_2, \ldots, Q_m, P_Z, W) \\ &\ldots \\ P_m &= G_m(Q_1, Q_2, \ldots, Q_m, P_Z, W). \end{aligned}$$

This system includes m potential equations, each equation having the price of the trip, the total travel cost, as the dependent variables. The independent variables include a vector of quantities of trips demanded and demand shift variables. Note that including the quantities of visits taken in each equation captures cross quantity effects. Omission of these cross-quantity effects even in single equation models can lead to bias.

Although we choose to display the utility maximization outcome in terms of an inverse demand system, the model could also be expressed in terms of a demand system. An intuitive explanation of the inverse demand system is that the model is predicting marginal willingness to pay conditional on the goods purchased.[1]

In order for the system of demand equations to generate single welfare estimates from price changes, the cross-quantity terms must be symmetric (from the Slutsky conditions).[2] If this condition is not met, single valued welfare estimates of multiple price changes are not possible. Multiple price changes can only be evaluated by examining the consumer surplus across all affected demand functions. In order for the resulting answer to be independent of which equations one integrates first (and arbitrary decision), the cross-quantity effects must be symmetric. Since valuation of multiple destination trips frequently involves multiple price changes, this assumption is critical if the model is to be used for welfare purposes.

The consumer surplus for visits to site i is:[3]

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[1] One justification for using an inverse demand function is that we observe people taking 0,1,2,... trips and we are trying to estimate their marginal willingness to pay for the last trip. This willingness to pay is proxied by the travel cost per trip with an error term added on. Of course, the error structure of an inverse demand function is quite different from the assumed error structure of a traditional demand function.

[2] The symmetry conditions require the dh(i)/dP(j) = dh(j)/dP(i) where h(k) is the compensated demand function. The Slutsky equation defines dh(j)/dp(i) = dx(j)/dp(i) + (dx(j)/dy)*x(i). If the income term on the right hand side of the Slutsky equation is near zero, then it follows that dx(i)/dp(j) = dx(j)/dp(i) is approximately correct.

[3] We estimate the net value of goods in this paper using consumer surplus. In most circumstances, consumer surplus will yield acceptably close results to compensated measures (see Willig [1976]). Precise compensated measures could be estimated by deducing the underlying indirect utility function which generates (2).

$$\text{(3)} \quad CS(i) = \int_{Q_i}^{0} G_i(Q_1, Q_2, \ldots, q_1, Q_m P_Z, W)\, dq_i - P_1 Q_i.$$

Equation (3) can be used to value the quantity of Q_i of good i. This computation would be identical to a demand model without multiple destination sites except for the presence of the cross-quantity effects from the packages. If the multiple site trips affect the marginal value of single destination trips, then the traditional demand model of even single site trips (which exclude or fail to uniquely identify multiple destination trips) can be biased.

The welfare value of a site is the value of the demand system with the site minus the value of the demand system without the site. Removing any one site, in this case, involves eliminating all visits which include that site. Thus, one loses single destination trips to that site as well as all multiple site visits which involve that site. The removal of a site therefore involves many price changes (not just the single destination price). For example, suppose that site 1 were involved in k packages in addition to individual visits to site 1. The value of this site, measured through the impact of these multiple price changes, is:

$$\text{(4)} \quad \int_c \sum_{i=1}^{k+1} G_i(Q)\, dQ_i - \sum_{i=1}^{k+1} P_i Q_i,$$

where c is a line integral evaluated along path c between the initial quantity vector purchased and the zero vector. Note that (4) is just an extension of (3) to a situation which involves multiple price changes. With a single price change, nonmarginal changes can be valued using only the affected single demand function. With multiple price changes, however, the entire system of demand functions is affected and therefore the line integral is required (see Just Hueth and Schmitz [1982]).

Assuming symmetry and choosing a convenient integration path in which to express this line integral, we can describe (4) in the following terms:

$$(5) \quad \int_{Q_1}^{0} G_1(q_1, Q_2, \ldots, Q_m, P_Z, W)\, dq_1 - P_1 Q_1 +$$

$$\int_{Q_{n+1}}^{0} G_{n+1}(0, Q_2, \ldots, Q_n, q_{n+1}, Q_{n+2}, \ldots Q_m, P_Z, W)\, dq_{n+1} - P_{n+1} Q_{n+1} +$$

$$\int_{Q_{n+2}}^{0} G_{n+2}(0, Q_2, \ldots, Q_n, 0, q_{n+2}, Q_{n+3}, \ldots, Q_m, P_Z, W)\, dq_{n+2} - P_{n+2} Q_{n+2} +$$

$$\ldots +$$

$$\int_{Q_{n+k}}^{0} G_{n+k}(0, Q_2, \ldots, P_n, 0, \ldots, 0, q_{n+k}, Q_m, P_Z, W)\, dq_{n+k} - P_{n+k} Q_{n+k}.$$

There are k+1 integrals in (5). In the first simple integral, all quantities are set at their original level. This first integral is identical to the integral defining the value of single destination trips to site 1. Except for the presence of cross-price terms for packages, this first simple integral yields the same value as the approach of omitting multiple good purchases altogether. With each ensuing integral, the previously integrated quantities are set at their terminal value (zero). The sum of the k+1 integrals (from n+1 to n+k) reflects the total value of the multiple price change. Whereas the entire sum of integrals has a single welfare value, the value of the integral for each equation depends upon the path of integration which is arbitrary. Thus, one cannot ascribe a fraction of the total welfare of a multiple price change to any specific package.

Since prices must be positive over the integral from the beginning price to positive infinity, each integral in (5) is positive as long as at least one purchase is observed. Of course, not all packages will be observed. However, as long as some of the affected multiple good demand functions are observed and well-behaved, (5) will be strictly larger than (3). The consumer surplus for single purchase goods (3) will underestimate the true value of these goods (5).

The multiple destination demand model reveals an interaction between sites which is not evident in single visit demand systems. When a site is removed from a system, all the visits involving that site are removed. The presence of multiple destination visits adds a complementarity across sites which is not captured by the cross-quantity effects of single destination trips. Additional sites can increase the value of existing sites by making more multiple destination trips available. To the extent that multiple destination trips are important, traditional analyses which focus on single visits will underestimate the complementarity of the system.

This analysis identifies two sources of bias if multiple good purchases are omitted from demand models. First, single equation models of single purchases can be misspecified because of excluded cross-quantity effects. Second, single visit demand systems omit potentially important multiple destination demand equations leading to underestimates of total value and underestimates of the complementarity amongst sites.

III. MULTIPLE DESTINATION TRIPS TO BRYCE NATIONAL PARK

In this empirical application, we begin by estimating inverse travel cost demand functions for trips to Bryce. We take two traditional approaches by treating all trips to Bryce alike and by including only single destination trips. We also explore the impact of including cross-quantity effects. We then estimate the inverse demand system (2) for single and multiple destination trips. For all models, we calculate and compare the consumer surplus for Bryce.

Only Haspel and Johnson [1982], to our knowledge, have carefully collected data concerning the multiple destination itineraries chosen by users. This study was conducted at Bryce Canyon by the National Park Service. A small random sample of visitors to Bryce were asked what other destinations were visited on their trip. Many visitors to Bryce also visit other sites during the trip. Because everyone in the sample went to Bryce, the sample is not representative of the general population. Nonetheless, this sample should be able to reveal whether or not multiple destination trips are important to model correctly.

We assume that the travel costs per trip are a function of distance which is determined by one's residential location. For each of the m site types, there is a corresponding travel cost, P_i, which we assume is the same for everyone from a single was surprisingly long, including over 40 possible sites. Such a large set of alternatives presents a challenging task for our model because the number of possible combinations of sites is equal to 2^m-1 where m is the number of sites. Technically, with 40 sites, there are 1.1 trillion possible combinations of trips. We focus on four prominent destinations in this vicinity: Bryce Canyon, Grand Canyon, Arches, and Las

Vegas. Because Bryce and Zion are so close, we treat them as a single destination, Bryce.

Even with just four sites, there are 15 possible combinations of destinations that a user could choose (4 single destinations, 6 pairs, 4 triplets, and 1 quartet). Since everyone had to visit Bryce to be in the sample, the set of combinations in this sample is limited to eight. Technically, the demand system could include eight equations and each equation could include eight quantity (visit) variables including the own quantity. In this sample, two combinations are not relevant because they are not desired (visited) by any users. Of the six visited combinations, 72% of all trips just visit Bryce, 14% visit Bryce and Las Vegas, 7% visit Bryce, Grand Canyon, and Arches, 6% visit Bryce and Grand Canyon, and the remaining 1% visit Bryce and Arches or all four sites.

Because visitation to Bryce is infrequent (people generally come once per season or less) and the entire sample visited Bryce, it is not possible to estimate travel cost functions with individual data. We therefore turn to the traditional travel cost model and calculate aggregate visitation rates by origins. In this study, we define origins as counties. Using 1980 Census data, we compute visitation rates by dividing visits by population. Visitation rates were computed for each type of combination visit possible. Additional socioeconomic data such as median income, percent urban, and percent college graduates were also collected from the Census by county.

Because visitation from distant origins occurs very rarely, long-distance visits tend to involve different behavior (see Smith and Kopp [1980]). Although the exact boundary where this limit is reached is not known with precision, we assume that counties beyond 850 miles of Bryce should be excluded. A total of 473 counties are included. There are consequently 473 observations in each of the regressions. Some of these included counties had no observed visitors during the sample period.

In Table 1, the demand function for trips to Bryce is estimated three different ways. In the first equation, the own quantity variable is limited to single destination trips and cross-quantity effects are excluded. In the second equation, both multiple and single destination trips are added for the own quantity visit rate. In the third equation, the own-quantity is defined as only single destination trips and the cross-quantity effects of multiple destination trips are also included. For all equations in Table 1, the dependent variable is the round trip travel costs Bryce alone.

In this example, all three methods produce similar estimates of the own quantity effect. The coefficient on Bryce trips is similar across all three equations. Thus, if one were solely interested in valuing single destination trips, this example suggests that excluding multiple destination trips entirely is satisfactory. The only cross-quantity effect which is statistically significant is the Bryce-Las Vegas trips which acts as a substitute for visiting Bryce alone.

In a system of multiple destination trips, travel costs across combinations will tend to be correlated. Come origins will have almost identical travel costs across the combinations. The resulting collinearity or prices poses problems in estimating standard demand functions. This problem or price collinearity is less serious with an inverse demand system because visitation rates (as opposed to prices) tend to vary independently of each other. Further, with a linear system, it is easier to calculate the welfare values of multiple price changes using an inverse demand system because the choke quantity is always zero whereas the choke price would have to be

TABLE 1

INVERSE TRAVEL COST DEMAND FUNCTION TO BRYCE[a]

Dependent Variable: TRAVEL COST TO BRYCE

Independent Variable	Definition of Bryce Visits: Bryce Only	All Trips	Bryce Only
Constant	1400 (33.14)	1389 (33.16)	1402 (32.54)
VISITS TO:			
Bryce	-2.30 (6.80)	-2.35 (7.36)	-2.30 (6.83)
Bryce Grand Canyon			.84 (0.15)
Bryce Arches			17.91 (0.72)
Bryce Las Vegas			-3.72 (3.07)
Bryce, Grand Canyon, Arches			-.56 (0.27)
Bryce, Grand Canyon, Arches, Las Vegas			43.63 (0.27)
Percent Urban	-18.71 (0.38)	-22.80 (0.47)	-31.51 (0.63)
Percent College Graduates	-1063 (4.00)	-937 (3.52)	-1028 (3.69)
R^2	.115	.128	.139

[a] T statistics are presented in parentheses.

calculated for each equation. A system of inverse demand equations was consequently estimated.

Using Limdep, we estimate the inverse demand system (2) imposing symmetry on the cross-quantity terms. As shown in Table 2, the six own quantity coefficients are all negative and significant. The own quantity coefficient on single destination trips remains close to the estimate in Table 1. Almost all cross-quantity terms are also significant and negative. The sign of the cross-quantity terms implies that trip combinations act as substitutes for one another. The marginal willingness to pay for trip type i falls the more trips of type j are taken.

Given that positive multiple destination trips are observed and that they are well behaved, we know that the single destination demand equation underestimates the consumer surplus embodied in the demand system. In order to gain some perspective on the magnitude of this effect, we compute the consumer surplus under the single destination trip demand function to Bryce and compare that estimate to the consumer surplus of all trips which involve Bryce. In all cases, we compute the consumer surplus associated with the average visitor to Bryce.

Assuming a travel cost rate of $.25 per mile including travel time, the consumer surplus in Table 1, using (3), is about $10 over the sample time period. The consumer surplus under the entire system of demand equations, however, is equal to $18. The single destination trips account for only 56% of the value of this particular site. The multiple destination trips, although they only account for slightly more than one-fourth of the observed trips, account for almost half of the value of the site in this example.

TABLE 2

Restricuted Estimates of the Inverse Demand Functions

for Multiple Destination Trips[a]

Dependent Variable: TRAVEL COST TO

Independent Variable	Bryce Only	Bryce Grand C	Bryce Arches	Bryce L Vegas	Bryce Grand C Arches	Bryce Grand C Arches L Vegas
Constant	1392 (33.16)	1568 (35.87)	1494 (35.80)	1786 (38.94)	1640 (40.83)	1895 (46.66)
TRIPS:						
Bryce	-2.36 (7.38)	-2.33 (7.01)	-1.92 (5.98)	-2.40 (6.90)	-1.84 (6.00)	-1.89 (6.09)
Bryce-GC	-2.33 (7.01)	-2.74 (3.41)	-1.37 (2.03)	-2.62 (5.55)	-2.00 (3.87)	-2.05 (3.28)
Bryce-AR	-1.92 (5.98)	-1.37 (2.03)	-4.64 (3.31)	-1.48 (2.91)	-2.71 (4.54)	-.87 (0.58)
Bryce-LV	-2.40 (6.90)	-2.62 (5.55)	-1.48 (2.91)	-3.20 (6.16)	-1.62 (3.72)	-2.17 (5.42)
Bryce-GC-AR	-1.84 (6.00)	-2.00 (3.87)	-2.71 (4.54)	-1.62 (3.72)	-2.62 (4.24)	-2.45 (4.59)
Bryce-GC AR-LV	-1.89 (6.09)	-2.05 (3.28)	-.87 (0.58)	-2.17 (5.42)	-2.45 (4.59)	-33.42 (3.77)
Percent Urban	-23.37 (0.48)	-116.0 (2.32)	86.1 (1.80)	-142.0 (2.70)	10.87 (0.24)	-36.17 (0.78)
Percent College	-966.0 (3.62)	-813.0 (2.93)	-1060.0 (4.00)	-890.0 (3.06)	-912.0 (3.57)	-912.0 (3.54)

[a] T statistics are presented in parentheses.

IV. CONCLUSION

This paper develops a defensible method to estimate the demand for multiple destination trips. Multiple site trips are treated like visits to additional sites. The demand for trips to each potential combination of sites is treated separately. A demand system can then be estimated to determine the value and effects of excluding any set of visits. Removing a site will cause the entire set of visits which involve that site to be eliminated. Even single site changes involve multiple price changes in this model. In general, restricting demand analyses to single destination visits underestimates the value of sites and the complementarity amongst sites.

This model of multiple destination trips is applied to Southwest National Parks. In this example, multiple destination trips act as substitutes for single destination trips. Although ignoring multiple destination trips does not bias the single destination demand functions, in this case, accurate site valuation requires multiple destination trips be treated uniquely. The consumer surplus for Bryce National Park indicates that the multiple destination trips contribute almost half of the value of the site. In this example, multiple destination trips cannot be ignored or treated as single destination trips without seriously underestimating site value.

Of course, multiple destination trips may not always be important. Because the Southwest sites are remote and tend to be clustered relatively close together, multiple destination trips are common. The northern Rocky Mountain parks and the parks of the Pacific Northwest probably also attract multiple destination trips. Foreign travel is another important example of multiple destination trips. The multiple destination travel cost model therefore has several important potential applications.

The multiple destination trip model can also be applied to study trips with multiple activities. There has been a growing interest in estimating the value of trip activities. If a trip involves a single activity, the estimation of the value of an activity involves a straightforward application of the simple travel cost model. However, if a trip involves multiple activities, one must confront the sample allocation problem which plagues multiple destination trips. A single trip with all its fixed costs generates multiple activities. By analyzing multiple activity trips as separate types of trips, as shown in this paper, a demand system for trips by activity type can be estimated. Using a line integral, the value of each activity could then be computed. The multiple destination model can consequently be applied to value activities in a multiple activity trip context as well.

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A MODEL OF THE IMPACTS OF WATER FLOWS, HATCHERY OPERATIONS, AND HARVEST REGULATIONS ON THE CALIFORNIA CENTRAL VALLEY SALMON FISHERY

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Abstract

In this paper we develop a model to simulate the impacts on the California Central Valley salmon fishery of changes in fresh water flows into and out of the San Francisco Bay Delta. The model also describes interactions among these water flow controls, hatchery operations, and harvest regulation. Traditionally, management of California's fresh water resources and anadromous fisheries have been undertaken separately, in the literature and in practice. We demonstrate the potential gains from a coordinated management approach.

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A MODEL OF THE IMPACTS OF WATER FLOWS, HATCHERY OPERATIONS, AND HARVEST REGULATIONS ON THE CALIFORNIA CENTRAL VALLEY SALMON FISHERY

1. INTRODUCTION

The San Francisco Bay/Delta ecosystem has become in recent years the object of intensive studies by state and federal agencies concerned with the allocation of water resources—water flows into and out of the Delta—and the management of commercial and sport fisheries. A major issue that stands out from this regulatory agenda is how to integrate the two kinds of regulation. Currently, these are addressed by separate agencies. The purpose of this paper—and of the larger project of which it is a part—is to explore the potential gains from joint, or cooperative, management. Specific objectives, at the start of the project in October, 1987, were (1) to determine the status of the existing fisheries, (2) to develop methods for measuring the economic value associated with preservation or enhancement of those fisheries, (3) to develop models of the relationships between water flow (and related quality) changes and the status of fisheries, and (4) to combine the economic methods with the fisheries models to determine the impacts on the value of fisheries of selected regulations.

Over the past year, we have completed an extensive review of the existing data on the status of Bay/Delta fisheries, with special emphasis on striped bass and salmon, including the abundant materials that were presented at the State Water Resources Control Board's (SWRCB) Hearings on Water Diversions from the San Francisco Bay/Delta over the period July-December, 1987. The review has enabled us to identify what is known about the fisheries, what are the main areas of dispute, and what are the competing hypotheses.[1] We have also completed work on the second objective, the development of methods for estimating the economic value of a change in fishery harvest or stock size.[2] The present paper describes a simple model of the behavior of the California salmon fishery in relation to changes in key control variables identified in our review: water flows into and out of the Delta, hatchery operations, and fishing regulations.[3] We note that the review has led to a shift away from an earlier focus on pollution discharges and toward fresh water flows. Since a major impact of changes in flows is on temperature and salinity and since temperature and salinity are significant elements of water quality, we remain interested in the links between water quality and fisheries. But we are approaching these through impacts of flows on quality, rather than impacts of discharges on quality. Another small departure from our original intentions, also dictated by the review of the literature, is an emphasis on the role of hatcheries. As we shall indicate later on, one hypothesis is that an observed decline in the population of natural or nonhatchery salmon is due primarily to the existence of the hatcheries, and the interaction between their operation and harvest regulations. This "mixed-stock hypothesis" is one focus of our modeling efforts.

The plan of the paper is as follows. In the next section we briefly review population trends in the Central Valley (CV) chinook salmon fishery. A feature of the presentation here is the construction of tables on both abundance and escapement, broken down by hatchery and nonhatchery fish, on an annual basis since 1953. Section 3 examines the causes of the trends. The emphasis is on environmental conditions (with an emphasis, in turn, on water flows), but we also look at hatchery operations and harvest regulation. Sections 2 and 3 are essentially a review of the literature, geared toward developing a framework and hypotheses for modeling. Sections 4 and 5 are the heart of the paper, a discussion of our modeling approach, with some preliminary simulations of impacts on the fishery of changes in the key control variables. A concluding section briefly summarizes major findings and indicates how they will be integrated with subsequent work on the cost of controls and the value of changes in commercial and sport harvests.

2. POPULATION TRENDS IN THE CENTRAL VALLEY SALMON FISHERY

Before 1952, no statistics were kept of actual salmon populations. Examination of CV salmon runs using the river gill-net catch as an indicator of population showed significant fluctuations throughout the 1864-1958 period (Skinner, 1962). This was based on the total weight of gill-net catches, which was then used to estimate the number of fish caught. Peak catches occurred at 8- to 30-year intervals and tended to be followed by poor catches midway between the peaks. After 1915, the gill-net catch exhibited a lower trend, which Skinner attributes to large increases in the ocean troll fleet as well as environmental changes connected with water development projects (Dettman, Kelley, and Mitchell, 1987). Researchers who have examined data on the CV commercial river catches from 1864 to 1957 have concluded that the chinook salmon population fell to low levels in the 1930s (presumably due to overfishing) and then recovered in the 1940s. Commercial fishing of salmon inside the Golden Gate has not been allowed since 1957 (Dettman, Kelley, and Mitchell).

Following Dettman and Kelley (1987), we have constructed an abundance measure for adult salmon for the years 1953-1986 as the sum of estimated ocean catch and adult escapement (the term *escapement* refers to those salmon which have successfully returned to the CV river/delta system to spawn). The ocean catch estimate is based on catches reported to the Pacific Fisheries Management Council (PFMC) by commercial and sport boats on the West Coast. The catch is then apportioned between the Sacramento and San Joaquin Rivers and other spawning sites on the basis of the location of reported catches and assumptions about how the various populations disperse in the ocean. Estimates of annual abundance are presented in Table 1. Total numbers of natural and hatchery salmon remained fairly steady at around 650,000 fish per year, with substantial year-to-year variation, until the most recent decade when the average has fallen to a bit under 600,000. Note, however, the sharp decline over this recent period in the natural population, nearly offset by a corresponding increase in the hatchery population.

The data on annual escapement are shown in Table 2. Like abundance, escapement has been more or less stable, at around 200,000 per year, with significant year-to-year fluctuation. The data for hatcheries are the estimates of hatchery-produced fish successfully returning to spawn; only a small fraction of these fish are used by the hatcheries to produce a new generation. The others spawn in the wild and enter the "natural" population which is therefore increasingly composed of fish with some hatchery ancestry. Moreover, note that hatchery production has recently increased both in absolute numbers and as a proportion of total escapement, as it has for abundance.

The composition of the CV salmon run has changed during this period. The main stem Sacramento River runs have decreased since the 1940s, but the Feather and American River runs have both increased. Both of the latter rivers have compensated for loss of habitat due to dam construction with the construction of major hatcheries; the Sacramento River runs are more dependent on natural reproduction. There are four distinct runs in the CV system, distinguished by the timing of the upstream migration of the adult salmon. The fall run is by far the most important, and it comprises the entire surviving San Joaquin run. The late fall, winter, and spring runs are only in the Sacramento River and have represented between 30 percent (1969) and 6 percent (1979) of total escapement over the past two decades [U. S. Fish and Wildlife Service (USFWS), 1987]. Research and discussion on the effects of environmental changes in the Delta on the salmon population have focused almost exclusively on the fall run. In addition, the age structure of the population appears to have changed. Early in the

Table 1

Estimated Abundance of Adult Central Valley Salmon by Year

Year	Population: Total	Population: Natural[a]	Population: Nimbus and Feather hatcheries	Natural as percentage of total
	thousands			percent
1953	983.5	983.5	0.0	100.00
1954	1,053.2	1,053.2	0.0	100.00
1955	927.0	927.0	0.0	100.00
1956	763.2	763.2	0.0	100.00
1957	396.7	396.6	0.1	99.97
1958	563.0	561.3	1.7	99.70
1959	868.1	865.7	2.4	99.72
1960	848.0	845.6	2.4	99.72
1961	741.9	729.6	12.3	98.34
1962	621.4	603.5	17.9	97.12
1963	758.3	734.5	23.8	96.86
1964	781.3	759.5	21.8	97.21
1965	666.3	646.8	19.5	97.07
1966	524.7	516.1	8.6	98.36
1967	431.9	420.5	11.4	97.36
1968	694.5	672.3	22.2	96.80
1969	917.7	888.5	29.2	96.82
1970	720.4	675.1	45.3	93.71
1971	667.9	624.1	43.8	93.44
1972	662.9	600.9	62.0	90.65
1973	992.4	757.3	235.1	76.31
1974	702.5	484.6	217.9	68.98
1975	642.6	489.0	153.6	76.10
1976	642.7	536.5	106.2	83.48
1977	687.2	548.6	248.6	79.83
1978	587.8	268.4	319.4	45.66
1979	693.9	379.4	314.5	54.68
1980	621.4	371.9	249.5	59.85
1981	760.0	385.3	374.7	50.70
1982	947.2	658.6	288.6	69.53
1983	511.8	304.1	207.7	59.42
1984	534.7	371.1	163.6	69.40
1985	b			
1986				
Average				
Total	716.1	619.4	96.7	86.50
1953-1967	728.6	720.4	8.1	98.88
1968-1977	733.1	627.7	105.4	85.62
1978-on	665.3	391.3	274.0	58.81

[a]Natural refers to salmon not from the Nimbus and Feather hatcheries and therefore includes other hatcheries for which specific data are not available.

[b]Blanks indicate no data available.

Source: David H. Dettman and Don W. Kelley. *The Role of Feather and Nimbus Salmon and Steelhead Hatcheries and Natural Reproduction in Supporting Fall Run Chinook Salmon Populations in the Sacramento River Basin*, State Water Resources Control Board Hearings Document 8-4/559 (Tables IV-2 and III-4, based on ocean retrieval of coded wire-tagged salmon in commercial and sport fisheries). Sacramento, California: SWRCB, July, 1987.

Table 2

Estimated Salmon Escapement for Sacramento River Fall Run by Year

Year	Escapement			Natural as percentage of total
	Natural[a]	Nimbus and Feather hatcheries	Total	
	thousands			percent
1953	500.0	0.0	500.0	100.00
1954	400.0	0.0	400.0	100.00
1955	365.0	0.0	365.0	100.00
1956	145.0	0.0	145.0	100.00
1957	101.0	0.0	101.0	100.00
1958	234.3	0.7	235.0	99.70
1959	418.0	1.0	419.0	99.76
1960	414.0	1.0	415.0	99.76
1961	243.2	4.8	248.0	98.06
1962	243.6	7.4	251.0	97.05
1963	282.5	9.5	292.0	96.75
1964	294.4	8.6	303.0	97.16
1965	181.2	7.8	189.0	95.87
1966	183.4	3.6	187.0	98.07
1967	151.9	6.1	158.0	96.14
1968	180.3	9.7	190.0	94.89
1969	253.5	14.1	267.6	94.73
1970	181.5	19.9	201.4	90.12
1971	172.5	20.8	193.3	89.24
1972	117.5	20.0	137.5	85.45
1973	190.2	72.6	262.8	72.37
1974	147.6	81.6	229.2	64.40
1975	131.0	56.1	187.1	70.02
1976	147.4	41.2	188.6	78.15
1977	150.8	44.7	195.5	77.14
1978	53.8	100.1	153.9	34.96
1979	125.4	95.6	221.0	56.74
1980	94.0	81.9	175.9	53.44
1981	99.1	131.0	230.1	43.07
1982	129.2	76.8	206.0	62.72
1983	72.3	82.0	154.3	46.86
1984	125.0	79.0	204.0	61.27
Average				
Total	204.0	33.7	237.7	85.83
1953-1967	277.2	3.4	280.5	98.80
1968-1977	167.2	38.1	205.3	81.46
1978-on	99.8	92.3	192.2	51.95

[a]Natural refers to salmon not from the Nimbus and Feather hatcheries and therefore includes other hatcheries for which specific data are not available.

Source: David H. Dettman and Don W. Kelley, *The Role of Feather and Nimbus Salmon and Steelhead Hatcheries and Natural Reproduction in Supporting Fall Run Chinook Salmon Populations in the Sacramento River Basin*. State Water Resources Control Board Hearing Document 8-4/559 (Table IV-2, based on ocean retrieval of coded wire-tagged salmon in commercial and sport fisheries). Sacramento, California: SWRCB, July, 1987.

century, 4- and 5-year-old fish were common in both the ocean and spawning populations; in the past 10 years, the age composition of returns to hatcheries has been mainly 3-year-olds with a significant percentage of 2-year-olds (Dettman, Kelley, and Mitchell). Less is known about the age structure of the natural returns.

3. EXPLAINING THE TRENDS: SOME TENTATIVE HYPOTHESES

The object of this section is to review the evidence on how environmental conditions, hatchery operations, and harvest regulations have affected the fishery, in order to develop a framework for modeling. We also consider the mixed-stock hypothesis, described below.

Environmental Conditions

Destruction of Upstream Habitat

Salmon spawn in shallow gravel areas (redds) upstream of the Delta. In some cases, salmon have been denied access to redds because of dams; in others, the redds have been destroyed or polluted by land development or by industrial and agricultural development. Loss of redds breaks the life cycle at the point of reproduction. Adult spawners are unable to lay their eggs in a proper environment; hence, the next generation is either nonexistent or has drastically reduced survival rates. There is wide agreement that habitat loss and destruction have been extremely important factors in the decline in the population of wild salmon.

Water Flows

Our review of the literature suggests that the volume of water flowing in the Sacramento and San Joaquin Rivers and through the Delta is currently the environmental condition of greatest significance to the salmon. It affects abundance through a number of different mechanisms and is strongly influenced by regulatory action. Flow volumes at different times and places depend not only on river flows but also on diversions and exports for agricultural, industrial, and municipal use.

USFWS research has examined the relationship between spring flow volumes and survival of out-migrating smolts. April-June is the time period most crucial for out-migrating smolts in the fall run. For the 1979-1986 period, there was a correlation coefficient of 0.90 between April-June Sacramento River flow at Rio Vista and smolt abundance as measured through a midwater trawl of unmarked smolts at Chipp's Island. This correlation is only for smolt abundance and does not directly measure mortality and survival. In an effort to shed light on the relationship between flow and *survival*, as opposed to *abundance*, a correlation analysis was also performed for the relationship between mean daily flow at Rio Vista during the time of migration and the survival rate for tagged smolts as measured through a midwater trawl at Chipp's Island. A correlation of 0.97 was found.

To go beyond the simple correlation, i.e., to explain the relationship between flow and survival in a way that can be useful for policy analysis, we need to focus on the mechanisms by which the level and timing of CV river system flows influence salmon mortality. These include water temperature, predation, diversion and pumping, food availability, and water quality.

Water Temperature

High spring water temperatures can be lethal to fry. Even at sublethal temperatures, salmonids need significantly more food to survive than at lower temperatures. In the Sacramento River, spring water temperatures above 55°F. begin to trigger undesirable effects on chinook juveniles (USFWS; Dettman and Kelley; and State Water Contractors, 1987). Although there is general agreement on the importance of temperature, one source argues that there is no evidence of a causal link between flow and temperature despite the strong correlation (State Water

Contractors). Research conducted for the SWRCB hearings has carefully documented Sacramento River temperatures and finds that there has been a sustained upward shift since the 1976/77 drought (Reuter and Mitchell, 1987). In the Sacramento area, in particular, these increased water temperatures are not explained by climatological factors and are positively correlated with flows. This research concluded that the major mechanism for reducing June water temperatures would appear to be increased flow.

Predation

Increased predation of young salmon by squawfish and striped bass occurs because of clearer water and greater concentration of young during low flows (Stevens and Miller, 1983). It appears that greater flows will increase survival for this reason although we have found no evidence on the magnitude of this effect.

Diversion and Pumping

Salmon are diverted from the main stream of the Sacramento River through the Delta cross channel and the Georgiana Slough at Walnut Grove in proportion to the relative volume of flows of the Sacramento River and the diversions (USFWS). Survival of salmon diverted at Walnut Grove can be expected to be decreased by longer migration routes, higher water temperatures, increased predation, greater agricultural diversions, and a more complex channel configuration, making it difficult for smolts to find their way to sea. Further, once smolts successfully traverse the Delta and reach the lower San Joaquin River, they are likely to find reverse flows on the Mokelumne River and even the San Joaquin River itself due to the operation of the pumping plants. Salmon following these reverse flows may suffer increased mortality due to entrainment at the pumping plants and to even longer migration routes. USFWS tested this by releasing hatchery smolts both above and below the diversion points and then tracking their survival. They found that, when the diversion rate was high, survival of smolts released upstream was 50 percent lower than for those released downstream of the diversion point when the Delta cross channel gates were open.

Food Availability

There is reduced intraspecies competition for food at high flow levels because of greater dispersal (Stevens and Miller). Also, there is some evidence that the population of neomysis, a prime food source for juvenile salmon, is affected by water flow conditions in the Delta (Williams and Hollibaugh, 1987; Knutson and Orsi, 1983). A long-term decline in phytoplankton, in turn, the food source for neomysis, caused by flow changes is thought to be an important causal mechanism.

Water Quality

Toxicity and other manifestations of industrial, agricultural, and residential discharges presumably have negative effects on the salmon population through direct mortality and through effects on the lower trophic levels such as neomysis and phytoplankton. We have, however, found no direct evidence of the effects of water quality on the salmon population.

Hatchery Operations

In addition to environmental conditions in the Delta and upstream, the operation of hatcheries has been an extremely important determinant of the size and composition of the salmon population. As noted in Tables 1 and 2, hatchery salmon have become more important over time in supporting the fall run on the Sacramento, accounting in some years for over 50 percent of returning adult salmon. Hatcheries have a much higher success rate in the survival of salmon eggs to fry because of their control over the condition of spawning gravels, water temperature, food supply, and predation. In recent years, the Feather, Nimbus, and Mokelumne hatcheries have increasingly been trucking smolts to the lower Delta or Suisun Bay. This increases survival still further; the escapement rate for these hatcheries is between 2 and 10 times that of hatcheries which do not truck their fish (though it is not necessarily true that trucking is the sole reason for the difference). The main negative consequence of this practice is the increased probability of straying; fish which have been trucked are much more likely to fail to return to the hatchery (USFWS).

The chief risk to hatchery populations is disease, which can do tremendous damage to a year's population because of the close proximity in which the fish are kept. Disease can also be a problem because the genetic makeup of hatchery fish is more uniform than that of natural stocks, leaving less room for resistance.

Fishery Regulations

The third factor directly affecting the salmon population is the regulation of the fishing harvest. The agency charged with regulating the catch of both commercial and sport fishing is the PFMC. It has a wide range of regulatory instruments available, including temporal and geographic closures of fishing grounds, catch limits, and equipment regulation. The PFMC manages the salmon population for California, Oregon, Washington, and Alaska and coordinates salmon regulation with Canada. The agency attempts to manage the commercial and sport catches so as to allow sufficient spawning stock for population maintenance. Their target for CV chinook salmon escapement of approximately 180,000 has been met, or nearly met, in virtually all years since 1953 (see Table 2). Note that, if regulators take account of low populations caused by adverse environmental conditions and restrict the catch, this mitigates the effect of environmental conditions on adult escapement. Escapement may also be stabilized by liberal fishing rules under favorable environmental conditions.

The ocean catch of CV salmon has ranged between a minimum of 200,800 fish in 1967 and a maximum of 684,500 in 1981 and has averaged about 420,000 fish per year (Table 3). Casual examination of the data indicates that catches have been low in years with low populations. It is not clear from examination of fishing season regulations to what extent this is a result of effective regulation and to what extent it is due to more difficult fishing in years with low populations. In addition, USFWS estimates that 35,000 adult salmon are landed each year by the inland sport fishery. There is no good record-keeping system and this is only a very rough estimate.

The Mixed-Stock Hypothesis

The data presented above indicate that the CV system has produced fewer and fewer salmon outside the hatcheries over the past 30 years. One explanation, suggested above, is that, due to adverse shifts in environmental conditions, salmon spawning in the wild have not produced enough offspring to maintain the population. According to this explanation, without hatchery production (and the increased survival of that production due to release near San Francisco Bay), the salmon fishery would already have experienced a precipitous decline. An alternative explanation for the decreasing numbers of natural or nonhatchery salmon is the mixed-stock hypothesis: The combined effect of hatchery operation and regulation of the salmon fishery may be acting in such a way as to steadily decrease both the proportion and the absolute numbers of nonhatchery fish (Hilborn, 1985). If a greater percentage of hatchery eggs survive each year than nonhatchery eggs, the overall proportion of hatchery fish in the ocean population will rise. This is reasonable because controlled temperature conditions, food supplies, and lack of predators in the hatcheries give these eggs a higher chance of survival, and the practice of three hatcheries of trucking smolts to the Delta increases the odds even more. If regulators base the allowable ocean catch on the goal of maintaining a reasonably steady spawning population, then increases in

Table 3

Estimated Ocean Catch of Adult Central Valley Salmon

Year	Ocean catch: Total	Ocean catch: Nimbus and Feather hatcheries	Ocean catch: Natural[a]	Natural as percentage of total
	thousands			percent
1953	384.5	[b]	384.5	
1954	560.2		560.2	
1955	504.6		504.6	
1956	586.7		586.7	
1957	276.7	0.1	276.6	99.96
1958	274.5	1.0	273.5	99.64
1959	390.4	1.4	389.0	99.64
1960	363.6	1.4	362.2	99.61
1961	487.2	7.5	479.7	98.46
1962	364.4	10.5	353.9	97.12
1963	457.4	14.3	443.1	96.87
1964	460.0	13.2	446.8	97.13
1965	468.3	11.7	456.6	97.50
1966	327.9	5.0	322.9	98.48
1967	200.8	5.3	195.5	97.36
1968	400.7	12.5	388.2	96.88
1969	459.4	15.1	444.3	96.72
1970	390.8	25.4	365.4	93.50
1971	349.6	23.0	326.6	93.41
1972	434.3	42.0	392.3	90.33
1973	669.2	162.5	506.7	75.72
1974	438.5	136.3	302.2	68.92
1975	396.0	97.5	298.5	75.37
1976	374.7	65.0	309.7	82.66
1977	452.4	93.9	358.5	79.25
1978	387.4	219.3	168.1	43.39
1979	452.5	218.9	233.6	51.62
1980	419.0	167.6	251.4	60.01
1981	448.3	243.7	204.6	45.64
1982	684.9	211.8	473.1	69.08
1983	274.3	125.7	148.6	54.16
1984	258.8	84.6	174.2	67.31
1985	416.3			
1986	550.6			
Average	422.5	63.0	355.7	85.09
1953-1967	407.1	4.8	402.4	98.83
1968-1977	436.6	67.3	369.2	84.58
1978-on	432.5	181.7	236.2	57.99

[a]Natural refers to salmon not from the Nimbus and Feather hatcheries and therefore includes other hatcheries for which specific data are not available.

[b]Blanks indicate no data available.

Source: David H. Dettman and Don W. Kelley. *The Role of Feather and Nimbus Salmon and Steelhead Hatcheries and Natural Reproduction in Supporting Fall Run Chinook Salmon Populations in the Sacramento River Basin.* State Water Resources Control Board Hearings Document 8-4/559 (Table II-4, based on ocean retrieval of coded wire-tagged salmon in comercial and sport fisheries). Sacramento, California: SWRCB, July, 1987.

population due to greater survival of hatchery fish will result in larger ocean catches. The same number of spawners will return to the Central Valley, but fewer will be wild. This process will continue with the result that the population remains more or less constant but the population of nonhatchery fish declines.

4. A DYNAMIC MODEL OF THE FISHERY

In this section we develop what we believe is the simplest possible model of the interactions among harvest, hatchery, and water flow controls in an age-structured salmon population. The purpose is to show how changes in one or more of the controls affect the fish population, or a relevant part of the population, or the harvest in a given year. For example, given a target escapement, and hatchery capacity, how would a decrease in water exports from the Delta affect the harvest in the year of the decrease and for (say) the next 10 years? And how would these results be affected by a change in hatchery capacity, or target escapement, or in precipitation over one or more years in the period? With the aid of the model, we can answer these and many other questions presumably of interest to decisionmakers in the fishery and water resource management agencies.

An advantage of the model, which we shall demonstrate as we proceed, is that it is very transparent in the sense that impacts of changes in any of the controls are readily traced. Further, the model is easy and inexpensive to run, allowing the user to explore a wide variety of regulatory or policy scenarios. A corresponding disadvantage is that the model does not realistically reproduce the behavior of the fishery in the kind of detail that might be desired for some purposes. For example, it cannot show the effect on smolt survival in the Delta of additional releases of fresh water from a particular upstream dam site at a particular time of year. Similarly, it does not distinguish among the several different hatchery sites, specifying only an aggregate hatchery capacity. Thus, the model is not appropriate for studying the impacts of changes at the "micro" level. But for a quick, transparent view of interactions among a few key "macro" controls and population variables (the purpose for which it was designed), we feel it can be useful. We should note also that the key macro relationships are based on solid micro functions. The number of smolts reaching the Bay in a given year, for example, is a function of target escapement, hatchery intake, and fresh water flows into and out of the Delta—in reality and in our model. In the model, the aggregate functional relationships are estimated from "observations," or runs, of a very detailed micro model of the fishery as we shall explain below.

We turn now to the model. We first display the basic structure and then present and discuss the results of illustrative policy simulations. It is convenient to distinguish two sets of model equations. The first describes the relationships among natural system parameters, policy variables, and elements of the salmon population (including the harvest) in a given year. The next provides the transition from one year, or salmon age class, to the next.

To begin, the ocean population of natural, or nonhatchery, salmon eligible to be caught is given by

(1a) $$\text{nat pop} = \%\ \text{nat esc}_2 \cdot \text{nat pop}_2 + \text{nat pop}_3 + \text{nat pop}_4,$$

where "nat" stands for natural; the subscripts 2, 3, and 4 are the salmon age classes; and % nat esc_2 is the exogenously given percentage of natural two-year-olds that escapes to spawn in the absence of fishing. We assume that only two-year-olds mature enough to escape are large enough to be legally retained by the ocean fishery: This is the first term on the right-hand side of equation (1a). The ocean population of hatchery salmon is similarly

(1b) $$\text{hat pop} = \%\ \text{hat esc}_2 \cdot \text{hat pop}_2 + \text{hat pop}_3 + \text{hat pop}_4,$$

where the "hat" stands for hatchery. The initial age distribution is exogenous, needed to start the model. In the absence of disturbances, it converges to an equilibrium. If the initial distribution is chosen to reflect historical averages, the convergence is very quick.

Total escapement in the absence of fishing, or potential escapement, is the sum of potential escapement of natural and hatchery fish; in symbols,

(2) $$\text{pot esc} = \text{pot nat esc} + \text{pot hat esc} \equiv \sum_{i=2}^{4} \%\ \text{nat esc}_i \cdot \text{nat pop}_i + \sum_{i=2}^{4} \%\ \text{hat esc}_i \cdot \text{hat pop}_i .$$

Thus far, we have been describing the population. Now we introduce a policy variable: target escapement (targ esc). This is the number of fish the regulatory authority wishes to allow to escape to replenish the fishery. From target escapement, the harvest is determined according to

(3) $$\text{harv} = \text{catch factor}(\text{nat pop} + \text{hat pop}),$$

where the catch factor is

$$1 - \frac{\text{targ esc}}{\text{pot esc}} .$$

Actual escapement, with fishing, is then given for naturally reproducing fish by

(4a) $$\text{nat esc} = (1 - \text{catch factor}) \cdot \text{pot nat esc}$$

and, for hatchery fish, by

(4b) $$\text{hat esc} = (1 - \text{catch factor}) \cdot \text{pot hat esc}.$$

Since commercial fishermen have no way of distinguishing between natural and hatchery-produced fish, we assume that the same catch factor applies to both.

From (fall) escapement, outmigrating nonhatchery smolts in the spring and summer of the following year are determined in the model according to a pair of equations which relate smolts, as the dependent variable, to hatchery intake, water flow variables, and escapement. The observations on which the regression estimates are based are not raw data, but rather data generated from repeated runs of a highly disaggregated simulation of the fall run (Biosystems: Hagar, Kimmerer, and Garcia, 1988; Kimmerer, Hagar, Garcia, and Williams, 1989). Two equations are, in fact, estimated in this fashion—one for the number of spawning fish and one for the number of smolts reaching the Bay as a function of the number of spawners. Each equation is separately estimated for each of three precipitation year types: critical, above-normal, and wet. The California Department of Water Resources also distinguishes dry and below normal years, but data limitations have thus far prevented us from estimating spawners and smolts for these year types. In our judgment, the three year types we have are sufficient to permit useful inferences about the interaction of water flows and the fishery, especially as we are able to include a critically dry year.

The equation for spawners is, in general functional notation,

(5) $$\text{spawners} = f(\text{targ esc}) - \text{surplus hatchery intake},$$

where surplus intake is defined as the excess of intake over a baseline level. In this formulation a positive (negative) excess intake reduces (increases) the number of naturally spawning fish.

The equation for smolts reaching the Bay is

(6) $$\text{nat smolts} = g(\text{spawners, inflow, exports}).$$

The specific functional forms and estimated coefficients are given in an Appendix. Here, we note only that the specification allows for density—dependent mortality. That is, as the number of escaping fish increases, the number of spawners increases more and more slowly. A similar sort of "diminishing returns" sets in in the relationship between spawners and smolts.

The inflow variable is based on flows (as represented in Biosystems) at three key locations: (1) above the Red Bluff Diversion Dam on the main stem Sacramento, (2) above the Thermalite Dam on the Feather River, and (3) on the American River near the Nimbus hatchery. We model flows, relative to a baseline, at all three locations in the aggregate for the April 1 to May 15 period—the most critical for outmigrating smolts. Thus, the flow variable is actual flow in cubic feet per second minus baseline flow, which varies with year type.

The exports variable represents the length of time that the Delta cross-channel gates are closed. We use dummy variables "0," "1," "2," and "3" to denote, respectively, closure for some time less than a month (depending on upstream flows), April 1 to May 1, March 15 to May 15, and March 1 to June 1.

Equation (6) describes smolts reaching the Bay. The USFWS (1987) estimates that 80 percent of these fish, in turn, reach the ocean, so the ocean population of nonhatchery salmon under two years old is given by

(7a) $$\text{nat pop}_1 = \text{nat smolts} \cdot 0.8.$$

Determination of hatchery production is somewhat simpler as little is left to chance—or nature. The hatcheries are treated like factories: They take in 16,660 adults and produce 12,250,000 juveniles, of which the great majority are trucked to the Bay and released. These numbers are based on historical averages for the three large hatcheries operated by the state: the Nimbus, Feather, and Mokelumne hatcheries.[4] Input and output levels can be changed to simulate changes in hatchery policy. There is some evidence that hatchery smolts released in the Bay have lower survival rates to the ocean than the 80 percent used for nonhatchery fish due, perhaps, to the sudden change in temperature they experience on release. The ocean population of hatchery salmon under two years olds is then given by

(7b) $$\text{hat pop}_1 = \text{hat smolts} \cdot 0.8 \cdot \theta, \quad 0 \le \theta \le 1$$

where θ is a parameter reflecting the poorer survival prospects of trucked hatchery fish. In the absence of reliable information to the contrary, we can simply set $\theta = 1$.

We are now ready to follow an age class of salmon, natural and hatchery, from one year to the next. The transition from one- to two-year-olds is straightforward. We assume, following Biosystems, that 7.74 percent of the smolts that reach the ocean (nat pop_1 and hat pop_1 in equations 7a and 7b) survive the approximately 15 months until age two:

(8a) $$\text{nat pop}_2 = \text{nat pop}_1 \cdot .0774$$

and

(8b) $$\text{hat pop}_2 = \text{hat pop}_1 \cdot .0774.$$

Recall that these immature fish cannot be harvested and do not spawn.

Survival from age two to age three is more complicated, since fishing activity and escapement come into the picture. Survival depends on three factors: (1) natural mortality, (2) escapement and fishing mortality, and (3) shaker mortality (shakers are undersize two-year-olds caught and released). With respect to (1), we follow Biosystems and assume a monthly mortality of 5 percent. Combined escapement and fishing mortality of two-year-olds is given by % nat $esc_2 \cdot$ nat pop_2, as explained following equation (1a). Shaker mortality is estimated by the PFMC as 28 for every 100 "legal" fish taken by the commercial fishery and 7 for every 100 taken by the sport fishery, with a weighted average of 24.5 (the weights based on commercial and sport catches). An expression for the surviving ocean population of three-year-olds is then given by

$$\text{(9a)} \qquad \text{nat pop}_3 = (.95)^{12} \cdot (\text{nat pop}_2 - \%\ \text{nat esc}_2 \cdot \text{nat pop}_2 - \text{harv} \cdot 0.245)$$

and similarly for hatchery fish by

$$\text{(9b)} \qquad \text{hat pop}_3 = (.95)^{12} (\text{hat pop}_2 - \%\ \text{hat esc}_2 \cdot \text{hat pop}_2 - \text{harv} \cdot 0.245).$$

Finally, survival from age three to age four depends on natural mortality, escapement, and the harvest. Natural mortality is, again, 5 percent of the population each month. Escapement of three-year-olds is potential escapement multiplied by the common population ratio of target to potential escapement as in equation (4a). The harvest is just the population (of three-year-olds) multiplied by the catch factor as in equation (3). An expression for the population of four-year-olds is then

$$\text{(10a)} \qquad \text{nat pop}_4 = (.95)^{12} \cdot \left(\text{nat pop}_3 - \frac{\text{targ esc}}{\text{pot esc}} \cdot \%\ \text{nat esc}_3 \cdot \text{nat pop}_3 - \text{nat pop}_3 \cdot \text{catch factor}\right)$$

and, for hatchery fish,

$$\text{hat pop}_4 = (.95)^{12} \cdot \left(\text{hat pop}_3 - \frac{\text{t arg esc}}{\text{pot esc}} \cdot \%\ \text{hat esc}_3 \cdot \text{hat pop}_3 - \text{hat pop}_3 \cdot \text{catch factor}\right). \tag{10b}$$

The model is now complete. With populations of natural and hatchery salmon in each age class, as given by equations (8a), (8b), (9a), (9b), (10a), and (10b), we can return to equations (1a)-(7b) and determine a new set of population, harvest, escapement, and smolt survival figures. To illustrate how the system works and how it can be used to shed light on the impacts of coordinated regulatory decisions, we present and discuss in the next section the results of several simulations.

Before proceeding with the simulations, however, we ought to say a few words about the relationship of this model to other approaches in the fisheries literature. The traditional approach to modeling the dynamics of a fish population was developed by Ricker (1954), Shaefer (1954), and Beverton and Holt (1957). In their model, the transition from one generation to the next is described by a relationship between spawning and recruitment, either exponential (Ricker) or quadratic (Shaefer; Beverton and Holt). Later work modified the traditional approach to consider multiple stocks in the same fishery with varying reproductive rates but continued to rely on the concept of an unfished equilibrium (Paulik, Hourston, and Larkin, 1967). Hilborn (1976) noted that salmon populations are almost never in equilibrium. As the relative sizes of the different stocks comprising the fishery change year to year, the optimal harvest rate also changes. He used stochastic dynamic programming to determine optimal harvest rules for each year as a function of stock sizes which, in turn, were stochastic outcomes. We too model what is in effect a disequilibrium situation; the difference is that we explicitly represent the factors which cause the fishery to remain in disequilibrium. Our model is built around the variability in harvests, hatchery operations, and hydrological conditions caused by both natural processes and human decisions. By explicitly representing the several steps involved in the process of getting from spawning to recruitment of mature fish, we are able to more realistically introduce the decision variables. For example, as we shall see in the next section, increasing inflow and decreasing exports produce a transparent and dramatic effect on contemporaneous smolt survival, followed a couple of years later by an increase in the harvest of mature fish.

Another important difference is the ability of our model to treat hatchery operations differently than the naturally spawning population. As noted above, the Ricker approach depends on the concept of an unfished equilibrium—the number of salmon in the ecosystem in the absence of human intervention. Because hatchery output is to some degree independent of the carrying capacity of the ecosystem and is quite responsive to management decisions independent of any "unfished equilibrium," the usefulness of this approach to model the Central Valley chinook population is limited.

5. QUANTITATIVE ANALYSIS: THE IMPACT ON THE FISHERY OF SELECTED AND COORDINATED REGULATORY DECISIONS

A baseline simulation of the system is presented in Table 4. By baseline, we mean that hatchery intake and release are set at the levels noted in the preceding section, target escapement is similarly at an historical average (in round numbers) of 200,000 fish, and water inflow and export are set to reflect "normal" operations of the upstream dams and Delta pumping stations for a given year type. The sequence of year types for the 10-year simulation is arbitrary but exhibits two consecutive critically dry years fairly early in the sequence to reflect recent California experience. Not surprisingly, the major impact of the dry years is on natural smolts reaching the

TABLE 4: Baseline Simulation

YEAR	LESS-THAN-2YR-OLD NATURAL	LESS-THAN-2YR-OLD HATCH	2 YR OLD NATURAL	2 YR OLD HATCH	3 YR OLD NATURAL	3 YR OLD HATCH	4 YR OLD NATURAL	4 YR OLD HATCH
1	9800000	9800000	758520	758520	304725	304725	38596	38596
2	9555862	9800000	758520	758520	302990	302990	38372	38372
3	9555862	9800000	739624	758520	303475	303475	38305	38305
4	3154308	9800000	739624	758520	294523	303707	38493	38493
5	3154308	9800000	244143	758520	295486	304669	37618	38791
6	5790666	9800000	244143	758520	63253	313240	42029	43335
7	9555862	9800000	448198	758520	87151	337138	11250	55713
8	9555862	9800000	739624	758520	180690	331507	14557	56313
9	9555862	9800000	739624	758520	306550	315734	25332	46476
10	5790666	9800000	739624	758520	293536	302720	38742	39903

YEAR	TOTAL POOL POP NATURAL	TOTAL POOL POP HATCHERY	POTENTIAL ESCAPEMENT NO FISHING	TARGET ESCAPEMENT	CATCH FACTOR	HARVEST	NATURAL ESCAPEMENT	HATCHERY ESCAPEMENT
1	419173	419173	490089	200000	0.59	496226	100000	100000
2	417214	417214	488155	200000	0.59	492558	100000	100000
3	415743	417632	486546	200000	0.59	490807	99612	100388
4	406979	418052	483185	200000	0.59	483534	98794	101206
5	357518	419312	433884	200000	0.54	418748	86967	113033
6	129697	432428	346985	200000	0.42	238119	53923	146077
7	143220	468702	369472	200000	0.46	280681	50570	149430
8	269209	463672	440198	200000	0.55	399903	75402	124598
9	405844	438062	488316	200000	0.59	498267	94477	105523
10	406241	418475	483998	200000	0.59	483923	98557	101443

AVERAGE HARVEST==> 428277

Table 4 (cont.)

YEAR	HATCHERY INTAKE	ESCAPEMENT- % NATURAL	ENVIRONMENTAL VARIATION AND CONTROLS: FLOW STATUS	ENVIRONMENTAL VARIATION AND CONTROLS: X-CHANNEL OPS	YEAR TYPE	SPAWNERS	NATURAL SMOLTS AT SAN PABLO BAY	HATCHERY PLANTS AT SAN PABLO
1	16660	50%	0	0	ABOVE NRML	153583	11944827	12250000
2	16660	50%	0	0	ABOVE NRML	153583	11944827	12250000
3	16660	50%	0	0	CRITICAL	151143	3942885	12250000
4	16660	49%	0	0	CRITICAL	151143	3942885	12250000
5	16660	43%	0	0	WET	152846	7238332	12250000
6	16660	27%	0	0	ABOVE NRML	153583	11944827	12250000
7	16660	25%	0	0	ABOVE NRML	153583	11944827	12250000
8	16660	38%	0	0	ABOVE NRML	153583	11944827	12250000
9	16660	47%	0	0	WET	152846	7238332	12250000
10	16660	49%	0	0	ABOVE NRML	153583	11944827	12250000

AVERAGE NATURAL ESCAPEMENT PERCENTAGE ==> 43%

Bay, followed a couple of years later by a steep decline in the harvest and the number and proportion of natural salmon escaping to spawn. Thus, smolt survival falls from nearly 12 million to under 4 million, the harvest from nearly 500,000 to under 250,000, and the proportion of escaping salmon not produced in hatcheries from 50 percent to 25 percent. Recovery of the system appears to be relatively rapid—by the second year following the impact in each case.

The next simulation looks at the effect of selectively increasing inflows and decreasing exports in just the dry years, all other controls remaining the same. Specifically, we increase aggregate inflows by 3,000 cubic feet per second for the April 1 to May 15 period and close the Delta cross-channel gates from March 1 to June 1. As shown in Table 5, the impact on population and harvest is dramatic. Smolt survival falls only to a little over 9 million, harvest to a little under 400,000, and nonhatchery escapement to 40 percent of the total. Intermediate levels of increased inflows and decreased exports in just the dry years lead in other simulations to intermediate impacts on population and harvest, perhaps not surprisingly.

These simulations illustrate the impact of flow controls dependent on the nature of the precipitation year. Another simulation illustrates the impact of what we might call "uncoordinated" controls. In this case we simply specify the increased inflows and decreased exports in all years, not just the dry ones. As shown in Table 6, results are very similar to those in the "coordinated" case. Providing more fresh water to the fishery in above-normal and wet years adds only a very little to smolt survival in those years and to later harvests. This is an important finding, because more fresh water for the fishery means less available to optimize dam operations upstream of the Delta and less available for export to agricultural users south of the Delta. At this point, we merely note these opportunity costs of increased flows. In a subsequent analysis, we shall provide estimates of the dollar value of the costs, to be balanced against the benefits of increased harvests.

TABLE 5: Simulation of Increased Flow in Critical Years

YEAR	TOTAL POOL POP NATURAL	TOTAL POOL POP HATCHERY	POTENTIAL ESCAPEMENT NO FISHING	TARGET ESCAPEMENT	CATCH FACTOR	HARVEST	NATURAL ESCAPEMENT	HATCHERY ESCAPEMENT
1	419173	419173	490089	200000	0.59	496226	100000	100000
2	417214	417214	488155	200000	0.59	492558	100000	100000
3	415743	417632	486546	200000	0.59	490807	99612	100388
4	406979	418052	483185	200000	0.59	483534	98794	101206
5	390600	419312	466966	200000	0.57	463029	94975	105025
6	314723	423499	437904	200000	0.54	401060	86801	113199
7	301940	434752	427005	200000	0.53	391641	80835	119165
8	272690	438289	435072	200000	0.54	384146	81746	118254
9	406145	438612	486784	200000	0.59	497680	94408	105592
10	406705	418943	484841	200000	0.59	485063	98558	101442

AVERAGE HARVEST==> 458574

ENVIRONMENTAL VARIATION AND CONTROLS

YEAR	HATCHERY INTAKE	ESCAPEMENT-% NATURAL	FLOW STATUS	X-CHANNEL OPS	YEAR TYPE	SPAWNERS	NATURAL SMOLTS AT SAN PABLO BAY	HATCHERY PLANTS AT SAN PABLO
1	16660	50%	0	0	ABOVE NRML	153583	11944827	12250000
2	16660	50%	0	0	ABOVE NRML	153583	11944827	12250000
3	16660	50%	3000	3	CRITICAL	151143	9285621	12250000
4	16660	49%	3000	3	CRITICAL	151143	9285621	12250000
5	16660	47%	0	0	WET	152846	7238332	12250000
6	16660	43%	0	0	ABOVE NRML	153583	11944827	12250000
7	16660	40%	0	0	ABOVE NRML	153583	11944827	12250000
8	16660	41%	0	0	ABOVE NRML	153583	11944827	12250000
9	16660	47%	0	0	WET	152846	7238332	12250000
10	16660	49%	0	0	ABOVE NRML	153583	11944827	12250000

AVERAGE NATURAL ESCAPEMENT PERCENTAGE ==> 47%

TABLE 6: Simulation of Increased Flow in All Years

YEAR	TOTAL POOL POP NATURAL	TOTAL POOL POP HATCHERY	POTENTIAL ESCAPEMENT NO FISHING	TARGET ESCAPEMENT	CATCH FACTOR	HARVEST	NATURAL ESCAPEMENT	HATCHERY ESCAPEMENT
1	419173	419173	490089	200000	0.59	496226	100000	100000
2	417214	417214	488155	200000	0.59	492558	100000	100000
3	422852	417632	493655	200000	0.59	499969	101057	98943
4	446870	416286	502953	200000	0.60	519921	103199	96801
5	422947	412824	478585	200000	0.58	486504	99086	100914
6	314503	418795	436530	200000	0.54	397331	87786	112214
7	310494	434943	435185	200000	0.54	402853	83117	116883
8	318604	436018	457077	200000	0.56	424428	88062	111938
9	446653	430918	505947	200000	0.60	530669	100245	99755
10	446081	412402	502922	200000	0.60	517084	103815	96185

AVERAGE HARVEST==> 476754

ENVIRONMENTAL VARIATION AND CONTROLS

YEAR	HATCHERY INTAKE	ESCAPEMENT- % NATURAL	FLOW STATUS	X-CHANNEL OPS	YEAR TYPE	SPAWNERS	NATURAL SMOLTS AT SAN PABLO BAY	HATCHERY PLANTS AT SAN PABLO
1	16660	50%	3000	3	ABOVE NRML	153583	13092901	12250000
2	16660	50%	3000	3	ABOVE NRML	153583	13092901	12250000
3	16660	51%	3000	3	CRITICAL	151143	9285621	12250000
4	16660	52%	3000	3	CRITICAL	151143	9285621	12250000
5	16660	50%	3000	3	WET	152846	8595248	12250000
6	16660	44%	3000	3	ABOVE NRML	153583	13092901	12250000
7	16660	42%	3000	3	ABOVE NRML	153583	13092901	12250000
8	16660	44%	3000	3	ABOVE NRML	153583	13092901	12250000
9	16660	50%	3000	3	WET	152846	8595248	12250000
10	16660	52%	3000	3	ABOVE NRML	153583	13092901	12250000

AVERAGE NATURAL ESCAPEMENT PERCENTAGE ==> 48%

As a final illustration of the uses of the model, we show how it can be used to simulate the workings of the mixed-stock hypothesis. Recall that this involves the expansion of hatcheries along with the maintenance of a steady spawning population, resulting in a declining proportion of nonhatchery fish in the population. Table 7 shows what happens when hatchery intake is expanded by 6,000 spawning fish, from 16,660 to 22,660, and the release of smolts to the Bay is increased by 6 million, to just over 18 million. (These increases are arbitrary, but the relationship between them is reasonable; there is evidence that a given increase in intake could produce a proportionally larger increase in smolts.) In the simulation, target escapement is kept at the baseline level of 200,000, and water flow controls are also unchanged. The harvest is substantially increased, from an average of 428,000 in the baseline case to 554,000, but the proportion of nonhatchery fish in the escaping population is down, from 43 percent to 35 percent—exactly as predicted by the mixed-stock hypothesis. We cannot conclude that a process like this is responsible for the observed decline in the proportion of nonhatchery fish, but our model does show that it is a possible explanation, at least in part.

6. CONCLUDING REMARKS

We have reviewed the current status of the Central Valley chinook salmon fishery, and also trends over the past several decades, distinguishing between naturally reproducing and hatchery fish. The main finding is that population and harvest levels have remained fairly steady with, perhaps, a small decline in just the past decade, but the small decline in total numbers has been accompanied by a dramatic decline in the natural population and a correspondingly dramatic increase in hatchery-produced salmon. The review of the evidence was followed by a discussion of possible explanations of the trends and implications for policy modeling. It appears

TABLE 7: Simulation of the Mixed-Stock Hypothesis

YEAR	TOTAL POOL POP NATURAL	TOTAL POOL POP HATCHERY	POTENTIAL ESCAPEMENT NO FISHING	TARGET ESCAPEMENT	CATCH FACTOR	HARVEST	NATURAL ESCAPEMENT	HATCHERY ESCAPEMENT
1	419173	419173	490089	200000	0.59	496226	100000	100000
2	417214	417214	488155	200000	0.59	492558	100000	100000
3	415743	454784	523698	200000	0.62	538073	92545	107455
4	397995	626779	586898	200000	0.66	675557	79492	120508
5	324808	623092	530812	200000	0.62	590749	64232	135768
6	96313	637508	441512	200000	0.55	401408	33146	166854
7	116028	674939	470030	200000	0.57	454407	33433	166567
8	240275	667222	537904	200000	0.63	570077	55830	144170
9	376092	642895	585951	200000	0.66	671181	72971	127029
10	374538	623306	580094	200000	0.66	653816	75807	124193

AVERAGE HARVEST==> 554405

ENVIRONMENTAL VARIATION AND CONTROLS

YEAR	HATCHERY INTAKE	ESCAPEMENT-% NATURAL	FLOW STATUS	X-CHANNEL OPS	YEAR TYPE	SPAWNERS	NATURAL SMOLTS AT SAN PABLO BAY	HATCHERY PLANTS AT SAN PABLO
1	22660	50%	0	0	ABOVE NRML	147583	11944827	18250000
2	22660	50%	0	0	ABOVE NRML	147583	11944827	18250000
3	22660	46%	0	0	CRITICAL	145143	3942885	18250000
4	22660	40%	0	0	CRITICAL	145143	3942885	18250000
5	22660	32%	0	0	WET	146846	7238332	18250000
6	22660	17%	0	0	ABOVE NRML	147583	11944827	18250000
7	22660	17%	0	0	ABOVE NRML	147583	11944827	18250000
8	22660	28%	0	0	ABOVE NRML	147583	11944827	18250000
9	22660	36%	0	0	WET	146846	7238332	18250000
10	22660	38%	0	0	ABOVE NRML	147583	11944827	18250000

AVERAGE NATURAL ESCAPEMENT PERCENTAGE ==> 35%

that water flows in the Delta—inflows and exports—may have a major impact on the fishery, along with hatchery operations and harvest regulations. We then developed a model of interactions among hatchery, harvest, and water flow controls in an age-structured population of natural and hatchery salmon. The model is used to show how changes in one or more of the controls can affect elements of the population or the annual harvest. Model parameters are chosen to reflect historical averages and observations in the Central Valley chinook salmon fishery so that simulation results are potentially useful to decisionmakers in the relevant fishery and water resource management agencies.

A particularly useful aspect of the model is that it is structured to permit the analysis of coordinated controls. For example, an illustrative simulation shows that increasing water inflows and decreasing exports just in dry years has a substantial impact on smolt survival and subsequent harvest. Maintaining the same flow levels in other years, however, produces very little additional benefit and, presumably, carries a substantial cost. In a forthcoming study we shall identify these and other control costs in some detail and provide dollar estimates along with similar estimates of the benefits of an increased salmon population and harvest.

FOOTNOTES

[1]For a detailed report on the striped bass fishery, see Callahan, Fisher, and Templeton (1989); for salmon, see Keeler, Fisher, and Hanemann (1989).

[2]For a discussion of methods and results, see Hanemann, Kanninen, and Loomis (1989).

[3]A similar modeling analysis of the striped bass fishery is presented in Callahan, Fisher, and Hanemann (1990).

[4]There is one other large hatchery, the Coleman, on the Sacramento, which does not truck smolts to the Bay and, consequently, produces a varying output.

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APPENDIX

THE ESTIMATION OF IN-RIVER RELATIONSHIPS

In this Appendix, we describe the estimation of equations (5) and (6) in the text. We use multiple regression analysis to project the output of spawning fish as a function of target escapement and hatchery intake and then nonhatchery smolts as a function of spawners and water flows. As stated in the text, the regressions are not intended to explain the underlying relationships or test a particular theory about them but rather to simulate the output of a much more complex simulation (the Biosystems model). Accordingly, what are referred to below as "observations" are, in fact, results of separate runs of the Biosystems model. Here, a caveat is needed. The Biosystems model is still under development and has not yet been fully validated. One difficulty, in particular, is the lack of adequate data to run the different precipitation years with different water temperatures during the spring. The temperature data used were for 1975, a wet year. Since high temperatures are correlated both with low flows and with high smolt mortality, it is likely that our estimates of smolt survival are biased upward in critically dry years and, perhaps, even in above-normal years.

Regression specifications and estimations (coefficients and associated t-statistics) are presented below for spawners and smolts in critical, above-normal, and wet years. For each year type, the number of salmon spawning in the wild (both natural and hatchery strays) is estimated as a quadratic function of escapement, with a separate adjustment for hatchery intake above the baseline level of 16,660. The quadratic formulation allows for density-dependent mortality; we hypothesize that the coefficient on escapement will be positive and, on escapement squared, negative and smaller in absolute magnitude. Similarly, in the equation for smolts, the coefficients on spawners should be large and positive and, on spawners squared, small and negative.

The other variables in the smolt equation are fresh water inflows and exports as described in the text.

1. CRITICAL YEARS

We used 1976 data to estimate relationships for critical years. Negative values for fresh water inflows (deviations from the baseline) are avoided because the Biosystems model would not run in these circumstances. The equations are

$$\text{(Thousand) spawners} = -1.275E+01 + \underset{(57.16)}{8.047E-04} \cdot \text{targ esc}$$

$$(A1) \qquad - \underset{(2.02)}{7.373E-11} \cdot (\text{targ esc})^2$$

$$- (\text{hatchery intake} - 16{,}660)$$

$R^2 = .999$

92 observations.

$$
\begin{aligned}
\text{Smolts} = & - 1.234E+03 + \underset{(11.58)}{9.425E-01} \cdot \text{inflow} - \underset{(-5.82)}{8.816E-05} \\
& \cdot (\text{inflow})^2 + \underset{(10.42)}{9.434E+02} \cdot \text{exports} - \underset{(-1.36)}{2.526E+01} \\
\text{(A2)} \quad & \cdot (\text{exports})^2 - \underset{(-15.66)}{1.969E-01} \cdot (\text{inflow} \cdot \text{exports}) + \underset{(11.61)}{5.715E+01} \\
& \cdot \text{spawners} - \underset{(-8.96)}{1.515E-01} \cdot (\text{spawners})^2 + \underset{(3.80)}{1.764E-03} \\
& \cdot (\text{inflow} \cdot \text{spawners}) + \underset{(6.78)}{3.700} \cdot (\text{exports} \cdot \text{spawners})
\end{aligned}
$$

$R^2 = .991$

92 observations.

2. ABOVE-NORMAL YEARS

The regressions here are based on 1978 data. To get a reasonable interpretation of the quadratic term in the presence of negative deviations, we defined -4,000 cubic feet per second from the baseline as "0" and modified all other flows accordingly. The equations are

$$\text{(Thousand) spawners} = -1.293E+01 + \underset{(406.0)}{8.328E-04} \cdot \text{targ esc}$$

(A3) $$- \underset{(-.2903E-01)}{1.431E-12} \cdot (\text{targ esc})^2$$

$$- (\text{hatchery intake} - 16{,}660)$$

$R^2 = .999$

128 observations.

$$\text{Smolts} = -5.021E+02 + \underset{(11.31)}{6.693E-01} \cdot \text{inflow} - \underset{(-6.645)}{3.574E-05}$$

$$\cdot (\text{inflow})^2 + \underset{(7.55)}{5.656E+02} \cdot \text{exports} - \underset{(-4.109)}{5.574E+01}$$

(A4) $$\cdot (\text{exports})^2 - \underset{(-11.89)}{9.562E-02} \cdot (\text{inflow} \cdot \text{exports}) + \underset{(25.37)}{9.288E+01}$$

$$\cdot \text{spawners} - \underset{(-16.17)}{1.999E-01} \cdot (\text{spawners})^2 + \underset{(4.682)}{1.290E-03}$$

$$\cdot (\text{inflow} \cdot \text{spawners}) + \underset{(3.049)}{1.167} \cdot (\text{exports} \cdot \text{spawners})$$

$R^2 = .993$

128 observations.

3. WET YEARS

The regression predicting the number of spawners is based on 1975 data. The equation is

$$\text{(Thousand) spawners} = -9.56 + \underset{(23.91)}{7.97E-04} \cdot \text{targ esc} - \underset{(1.055)}{7.50E-11} \cdot (\text{targ esc})^2 - (\text{hatchery intake} - 16{,}660) \quad \text{(A5)}$$

$R^2 = .998$

37 observations.

With respect to the smolt equation, when flows were high, as in 1975, the level of water exports made virtually no difference to survival (in the model, at least). For this reason, we omitted exports as an explanatory variable which, in turn, permitted us to obtain a good fit with fewer observations. Also, as in the above-normal year, we subtract 5,000 cubic feet per second from the Biosystems baseline to represent "0."

$$\text{Smolts} = -3.995\text{E}+03 + \underset{(15.29)}{1.924\text{E}+00} \cdot \text{inflow} - \underset{(-11.91)}{1.133\text{E}-04}$$

$$\cdot (\text{inflow})^2 + \underset{(5.545)}{4.424\text{E}+01} \cdot \text{spawners} - \underset{(-3.959)}{9.932\text{E}-02} \qquad \text{(A6)}$$

$$\cdot (\text{spawners})^2 + \underset{(2.705)}{6.652\text{E}-06} \cdot (\text{inflow} \cdot \text{spawners})$$

$R^2 = .979$

37 observations.

WELFARE MEASUREMENT AND PROJECT FINANCING

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Introduction

Option price (Weisbrod 1964; Schmalensee 1972; Bishop 1982) and the willingness-to-pay locus (Graham 1981, 1987) are two possible measures of benefits under uncertainty. Debate over which of these measures is the more appropriate has focused on the existence of contingent claims markets, the availability of fair insurance, and whether collection of state-dependent compensation payments is more or less feasible than state-independent payments. Mendelsohn and Strang (1984) argued that since complete, fair contingent claims markets do not exist and the government is generally unable to collect and administer state-dependent compensation payments, option price is the appropriate measure of benefits under uncertainty. Graham (1981) agreed that option price is the appropriate benefit measure when contingent claims markets do not exist and project financing is accomplished through state-independent payments, but argued that collection of state-dependent payments may be no more difficult than state-independent payments (Graham 1984).

We find ourselves in a dissatisfying situation where different measures are appropriate in different circumstances. Specifically, the choice of a welfare measure will depend on how the project is to be financed. There seems to be a consensus that if the project is financed using state-dependent payments, then the willingness-to-pay locus is appropriate. If state-independent payments are used to finance the project, then option price is the appropriate benefit measure[1]. What is needed is a more general welfare measure that is correct regardless of how the project is financed.

[1] A different view is expressed by Cory and Colby (Cory and Saliba 1987, Colby and Cory 1989) who argue that the expected value of the fair-bet point is the appropriate measure under most situations.

Project financing is not a peripheral issue. A potentially beneficial project could be made undesirable if financed in a way that distorts relative prices or aggravates inefficiencies in the allocation of risk. Conversely, a project could be made more attractive by improving the way in which it is financed. Cost-benefit analysis could be used to investigate the relative merits of alternative financing methods. The purpose of this paper is to develop a conceptual framework for performing such a cost-benefit analysis, and to identify individual benefit measures consistent with that framework. This is done under the assumption of uncertainty, but can be applied to a certain world as a special case. Consideration of project financing is as important in a certain world as in an uncertain one.

The organization of this paper is as follows: in the next section, a model of the project decision problem is developed that allows explicit consideration of project financing. Next, the potential Pareto improvement criterion is modified to accommodate consideration of how the project is financed, and a correct cost-benefit test that empirically measures whether the project results in a potential Pareto improvement is described. Given that cost-benefit test, it is possible to identify a correct benefit measure under uncertainty, i.e. a measure that allows performance of the cost-benefit test. Finally, the restrictive special cases where option price or the willingness-to-pay locus could be correct measures are identified.

A Model of Project Financing

Suppose that the government must decide whether or not to build a particular project. Here, the "project" need not be a construction project such as a dam, but could be any government action including a change in regulations, issuance of a permit, etc. The physical attributes of the project are described by the vector δ. The baseline (no project) situation is described by a different vector, $\bar{\delta}$. The task at hand is to determine whether the project should be built[2]. At the time the decision between δ and $\bar{\delta}$ is made, there is uncertainty over which of M possible states will occur. These states occur with probabilities $\pi_1,\ldots,\pi_M$. Following Graham (1987), assume that there are some costs associated with the project. These costs can be thought of as the government's budgetary costs of the project. These costs may depend on the state that occurs and are described by $C = (C_1,\ldots,C_M)$. Choosing $\bar{\delta}$ results in budgetary costs of 0 in each state[3].

How does the government raise the money to pay for these costs? Previous treatments have assumed that this money has been raised by collecting lump sum payments from individuals. Debate has centered over whether these payments should be state dependent or state independent. In the real world, however, projects are financed not with lump sum compensation payments, but with property taxes, income taxes, excise taxes, user fees, etc. Each of these tools introduces unique distortions in individual choices and has impacts on the risks faced by individuals. The method used to finance the project must therefore be explicitly modeled and included in the cost-benefit analysis.

Without the project, individuals will face a certain set of tax rates, user fees, etc., which can be viewed as a set of prices. Let ϕ be a vector

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[2] This paper is concerned with the evaluation of a single project. It does not address the issue of choosing from more than one available project.

[3] These costs do not include adverse non-monetary impacts to individuals. Such individual costs will be treated here as negative benefits.

that describes these prices. If the project is built, the government will raise the money to pay the budgetary costs, C, by increasing the tax rates, user fees, etc. faced by individuals. Let F be a vector that describes this new set of prices. Without the project, the government collects state-dependent revenues from individual i, i=1,...,N, equal to $R_i(I_i,\bar{\delta},\phi,s)$, where s is the state that occurs and $I_i = (I_{i,1},...,I_{i,M})$ is a vector of state-dependent wealth or income for individual i. With the project, the government collects revenues equal to $R_i(I_i,\delta,F,s)$. Notice that this characterization of a financing scheme is completely general. Elements of F could include any state-dependent or state-independent compensation payments that individuals were actually required to pay, but would also include any taxes, fees, etc. used to finance the project.

There will generally be a number of different methods that might be used to finance a project. In the same way that the government might consider more than one project, it might consider more than one way to finance each project. The project, therefore, is not completely specified without knowledge of how it will be financed, F. For example, a dam financed from general revenues is a fundamentally different project than the same dam financed by bonds that will be repaid with user fees. A complete characterization of the project would then be an ordered pair, (δ,F). A particular project (δ,F) is feasible if the financing method F generates enough revenues in each state to pay for the costs of δ, i.e.

1) $$\sum_i R_i(I_i,\delta,F,s) - \sum_i R_i(I_i,\bar{\delta},\phi,s) \geq C_s$$

for all states s. It should be noted that Graham (1987) also included in the definition of the project a description of how that project would be financed. However, he limited consideration to financing through state-dependent compensation payments. The model presented here is more general.

Explicit consideration of project financing is critical because the choice of a financing method will have important impacts on individual utility. Individuals may care whether a project is financed through property taxes or through user fees, even if the amount they expected to pay were the same. Let ex post utility for individual i be given by $U_i(I_{i,s},s,d,f)$ where $d=\delta$ or $d=\bar{\delta}$ and $f=F$ or $f=\phi$. Ex ante utility is then some function of the ex post utilities. For example, ex ante utility for individual i may be equal to the expected value of his or her ex post utility,

$$V_i(I_i,d,f) = \sum_s \pi_s U_i(I_{i,s},s,d,f). \qquad (2)$$

where $I_i = (I_{i,1},\ldots,I_{i,M})$. The expected utility assumption has come under some criticism lately, however, because it does not accurately model observed behavior under uncertainty. The results that follow will be developed without requiring the expected utility assumptions.

The Potential Pareto Improvement Criterion and Project Financing

How do we judge whether the project should be built? The potential Pareto improvement criterion is a value judgment concerning whether a project will result in an improvement in social welfare. Under certainty, it states that if it is possible for the winners from a project to both compensate the losers and pay for the budgetary costs of the project, so that everyone is better off with the project, then the project improves social welfare. Actual compensation is not required. It is only necessary that compensation be possible.

How would this criterion be implemented in the framework developed in the previous section? In other words, how do we determine which feasible projects (δ,F) represent potential Pareto improvements over the baseline $(\bar{\delta},\phi)$? Definition of an actual Pareto improvement is straightforward. A project (δ,F) is an actual Pareto improvement over the baseline $(\bar{\delta},\phi)$ if it is feasible and

3) $$V_i(I_i,\delta,F) \geq V_i(I_i,\bar{\delta},\phi)$$

for all i, with at least one strict inequality.

Definition of a potential Pareto improvement, however, is complicated by our explicit consideration of project financing. For a project (δ,F) to be a potential Pareto improvement over $(\bar{\delta},\phi)$, it must be the case that if compensation were actually paid, then an actual Pareto improvement would occur. The difficulty here is that actual payment of compensation would affect the revenues, $R_i(I_i,\delta,F,s)$, collected from each individual in each state. We must assure not only that compensation would leave everyone at least as well off as without the project, but also that the project is feasible after compensation is paid, resulting in the following definition:

A project (δ,F) is a potential Pareto improvement over $(\bar{\delta},\phi)$ if

1) it is feasible,

2) there exists a set of sure compensation payments, $\{g_i : i=1,\ldots,N\}$,

such that $$V_i(I_i-g_i,\delta,F) \geq V_i(I_i,\bar{\delta},\phi)$$

for all i, with at least one inequality, and

$$3) \qquad \sum_i \{g_i + R_i(I_i - g_i, \delta, F, s) - R_i(I_i, \bar{\delta}, \phi, s)\} \geq C_s$$

for all states s.

Thus, in order for a project (δ, F) to be a potential Pareto improvement over $(\bar{\delta}, \phi)$, it must be feasible with or without compensation.

The alert reader might object to the restriction in the hypothetical compensation test that compensation payments must be state-independent. It would seem that such a restriction would automatically disqualify the willingness-to-pay locus as a benefit measure. We shall see shortly, however, that this is not necessarily the case. For now, the reader is asked to accept this restriction on faith[4].

Empirical investigation of the potential Pareto improvement criterion is accomplished with a cost-benefit test. What form should such a test take, and what measure of benefits and costs should be used? We now have a measure of how much money an individual will actually pay for the project in each state, $R_i(I_i, \delta, F, s) - R_i(I_i, \bar{\delta}, \phi, s)$. This allows us to make clear the distinction between how much an individual is willing to pay for the project, and how much he or she must actually pay for the project. If an individual prefers (δ, F) to the baseline, then he or she will be willing to pay some additional amount of money, over and above what he or she actually will pay for the project. Consider the maximum sure amount that the individual would be willing to pay for the project, given that it will be financed using F. This amount could be thought of as a generalization of the concept of compensating variation,

[4] For an argument why this restriction is appropriate, see Ready (1989).

allowing for uncertainty and for an explicit consideration of how the project is financed, and might therefore be called the individual's generalized compensating variation (GCV_i). Generalized compensating variation can be defined for any project (δ,F) and will satisfy

4) $$V_i(I_i-GCV_i(\delta,F),\delta,F) = V_i(I_i,\bar{\delta},\phi).$$

GCV_i could represent a sure compensation payment in a hypothetical compensation test, which is consistent with our restriction that hypothetical compensation be carried out using state-independent payments. However, GCV_i does not contain enough information to perform a cost-benefit test for the project (δ,F). This is because it does not account for the change in government revenues that would occur if compensation were paid. In order to empirically determine whether a project constitutes a potential Pareto improvement over the baseline, it is necessary to know how compensation payments will change government revenues in each state.

A cost-benefit test for the project (δ,F) that does account for the affect of compensation on revenues is as follows. Define the net amount of money that could be collected in each state from an individual to pay for the project, given a particular sure compensation payment g_i, as

5) $$p_i(g_i,s) = g_i + R_i(I_i-g_i,\delta,F,s) - R_i(I_i,\bar{\delta},\phi,s).$$

For each g_i that satisfies

6) $$V_i(I_i-g_i,\delta,F) \geq V_i(I_i,\bar{\delta},\phi),$$

there will be a unique vector $p_i(g_i)=(p_i(g_i,1),\ldots,p_i(g_i,M))$. Define P_i as the set of all possible p_i vectors, $P_i = \{p_i(g_i) | g_i$ satisfies (6)$\}$. Finally, define Π as the set constructed by summation of all of the individual P_i's; $\Pi = \{\sum_i p_i(g_i) | p_i(g_i) \in P_i$ for each i$\}$. The process of constructing Π is exactly the same as constructing an aggregate willingness-to-pay locus from individual willingness-to-pay loci (see Graham 1981). The cost-benefit test for the project (δ, F) is then: is there a vector in Π that is at least as large as C in every state, and exceeds C in at least one state? If so, then the project (δ, F) is a potential Pareto improvement over the baseline, $(\bar{\delta}, \phi)$.

The correct measure of benefits for an individual (i.e. the measure that contains all of the information necessary for a cost-benefit test) is then the set P_i (or, more accurately, the boundary of the set P_i). In general, complete knowledge of P_i is necessary to be able to conduct a cost-benefit test for the project (δ, F). The set P_i can therefore be considered a general measure of benefits and costs under uncertainty with explicit consideration of project financing.

Benefit Measures and Special Cases

The set P_i is a cumbersome benefit measure and results in a difficult cost-benefit test. Fortunately, however, there is a situation where the cost-benefit test, and the measure of individual benefits, is significantly simplified. Suppose that we can make the following assumption:

7) $$-\frac{\partial R_i(I_i - g_i, \delta, F, s)}{\partial g_i} \leq 1 \text{ for all s.}$$

In other words, in each state, the change in the amount that the individual pays to the government due to a decrease in income in all states (an increase in the compensation payment) is less than that decrease in income. This assumption assures that the amount of money that can be collected from an individual, both in regular revenues and in compensation payments, will be maximized in all states by collecting (paying) the individual's generalized compensating variation[5]. Formally, $p_i(GCV_i)$ will be at least as great in every state as any other vector in P_i. This means that the vector $p^* = \sum_i p_i(GCV_i)$ will be at least as large in every state as any other vector in Π. Therefore, the cost-benefit test for the project (δ, F) becomes, is p^* at least as large as C in every state, and larger than C in at least one state? If so, then the project (δ, F) is a potential Pareto improvement over the baseline, $(\bar{\delta}, \phi)$. The correct measure of individual benefits then is a vector, $p_i(GCV_i)$, and the cost-benefit test is that the sum of the individual benefits, p^*, must exceed the costs of the project, C.

The vector $p_i(GCV_i)$ is the sum of 1) GCV_i = the maximum sure amount that the individual will be willing to pay for the project (δ, F) and 2) $R_i(I_i - GCV_i, \delta, F, s) - R_i(I_i, \bar{\delta}, \phi, s)$ = the amount that the individual would actually pay toward the project in each state, given that he or she has paid (or received) a compensation payment equal to GCV_i. If (7) holds, then $p_i(GCV_i)$ represents the maximum amount of money that could be collected from the individual for the project, given that compensation payments must be sure amounts, and tax revenues are collected according to F, and still leave the individual as well off as without the project. The vector $p_i(GCV_i)$ might therefore be called the maximum agreeable payment (MAP_i) for the project (δ, F).

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[5] To see this, notice that $\partial p_i(g_i, s)/\partial g_i = 1 + \partial R_i(I_i - g_i, \delta, F, s)/\partial g_i$, which will always be positive under (7). Therefore, $p_i(g_i, s)$ will be maximized in every state by setting g_i at its largest possible value.

Thus, in the special case where (7) holds, then the measure of benefits to an individual can be significantly simplified, from a set, P_i, of state-dependent vectors, to one particular state-dependent vector, MAP_i[6]. Still, we have as a benefit measure a vector, rather than a scalar. This is because the government must pay costs that are state-dependent, and so must collect different amounts of revenues in each state. The critical assumption here is that the government must collect revenues in each state that exceed costs in that state. The government is unable to make up deficits. Even though the hypothetical compensation payments are state independent, the benefit measure, MAP_i, is a vector because costs are (and therefore revenues must be) state dependent.

There are a number of special cases where the benefit measure could be characterized as a scalar. First, clearly, if there were only one possible state, we would be in a situation of certainty and the benefit measure would be a scalar. It should be noted, however, that even in this case, the correct benefit measure is different from the traditional definition of compensating variation, which does not explicitly consider the method of project financing. Second, if 1) the revenues paid by each individual are independently distributed from those paid by other individuals, 2) there are a large number of individuals, and 3) costs are certain, then the correct measure of benefits for an individual is a scalar equal to the expected value of MAP_i. By a large numbers argument, the government could collect sure revenues equal to the sum of the expected individual revenues.

A third case where the benefit measure is a scalar is where the

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[6] Recall that if (7) does not hold, then the correct individual benefit measure is the boundary of the set P_i.

government is able to absorb deficits and surpluses in revenues, and is risk neutral. Samuelson and Vickrey (1964) have argued that a government that undertakes a large number of projects may be able to pool the risks associated with each project. In the framework developed here, if the government can pool the revenue risks associated with a large number of projects, it could require only that expected revenues for each project exceed expected costs, and the individual benefit measure would again be $E[MAP_i]$.

It should be pointed out that the use of MAP_i as a benefit measure does not depend on any assumptions regarding the feasibility of collecting state-dependent, or state-independent, compensation payments, or the existence of complete contingent claims markets. Colby and Cory (1989) argued that it will typically be infeasible to collect either type of compensation payment. However, suppose that state-dependent compensation payments were implementable. Would this make the willingness-to-pay locus the correct measure of benefits? If state-dependent compensation payments that underlay a point on the aggregate willingness-to-pay locus are actually used to finance the project, then the willingness-to-pay locus is a correct measure of benefits. However, MAP_i would also still be a correct measure. Such a set of state-dependent compensation payments would constitute the method used to finance the project, and could be described by a financing method F^*. The benefit to an individual would be $MAP_i(\delta, F^*)$. Therefore, even though our hypothetical compensation test is limited to state-independent compensation payments, MAP_i correctly evaluates projects that are financed with state-dependent payments.

The existence or non-existence of complete contingent claims markets is also irrelevant for the choice of a benefit measure. While the existence of complete, fair, contingent claims markets would clearly influence how much an individual would be willing to pay for the project (δ, F), MAP_i would still be an appropriate measure of benefits. What contingent claims markets would do, however, is allow the government to insure against cost risks, so that it could finance the project using any method that generates the correct expected revenues. While this would allow consideration of more financing methods F, and consequently more projects (δ, F), each project should still be evaluated using MAP_i as the individual benefit measure.

Resource Valuation and Option Price

The practical implications of this discussion for conducting a cost-benefit analysis for a project are clear. The project is incompletely specified, and a cost-benefit analysis cannot be performed, without knowledge of how the project will be financed. If more than one financing method is possible, then more than one cost-benefit analysis needs to be conducted, and a separate estimate of net project benefits would be arrived at for each possible financing method. The implications for resource valuation are similar, but may be complicated by the hypothetical nature of the valuation problem. The value of a resource or amenity is usually defined as the net benefit from keeping the resource (avoiding its loss). A (usually) hypothetical project is envisioned that would preserve the resource. Given a complete description of this hypothetical project, the value of the resource is well defined as $\sum_i MAP_i$. A unique problem that may be encountered in valuing a resource or amenity, however, is the identification of the appropriate with-project and without-project financing schemes, F and ϕ. If the keep-resource/do-not-keep-resource decision is truly hypothetical, there may be little guidance over ϕ and/or F[7]. Here realism must be the guide. MAP_i is a valid measure of benefit only for a specific combination of ϕ and F. If unrealistic financing schemes are chosen for the analysis (i.e. financing schemes that would not actually be used) then the values of MAP_i arrived at will be of limited applicability. If F and ϕ are chosen to be as realistic as possible, the resulting values of MAP_i will be more widely applicable.

Two important special cases exist. Suppose that the budgetary costs of keeping the resource or amenity, C, are zero in every state. Preservation of the resource or amenity might impose negative benefits on some individuals (e.g. developers) but would not require government expenditures. In such a case, it is plausible that the with-project financing scheme, F, would be the same as the without-project financing scheme, ϕ. An individual's generalized compensating variation for the resource would be defined by

$$8) \qquad V_i(I_i - GCV_i(\delta,\phi),\delta,\phi) = V_i(I_i,\bar{\delta},\phi).$$

However, $GCV_i(\delta,\phi)$ is simply option price. Under what circumstances would option price be an appropriate measure of benefits?

Suppose that C=0 and F=ϕ, and that the revenues from an individual are not impacted by the presence or absence of the resource or amenity, i.e. $R_i(I_i,\delta,\phi,s) = R_i(I_i,\bar{\delta},\phi,s)$ for all s. This assumption would clearly not hold if ϕ included a user fee for access to the resource, but might hold in the absence of such a fee. Additionally, assume that $0 \leq -\partial R_i(I_i - g_i,\delta,F,s)/\partial g_i \leq 1$ for all s. Under these conditions, it can easily be shown that all of the

[7] If the keep/do not keep decision is truly hypothetical, however, one wonders whether the resource or amenity values being estimated will have any policy relevance.

elements of maximum agreeable payment have the same sign and that option price also has that same sign, but that option price is of equal or greater absolute magnitude than each $MAP_{i,s}$. That is, if $GCV_i(\delta,\phi) > 0$, then $GCV_i(\delta,\phi) \geq MAP_{i,s} \geq 0$ for all s. If $GCV_i(\delta,\phi) < 0$, then $GCV_i(\delta,\phi) \leq MAP_{i,s} \leq 0$ for all s. Finally, if $GCV_i(\delta,\phi) = 0$, then $MAP_{i,s} = 0$ for all s. If we make the more restrictive assumption that $\partial R_i(I_i-g_i,\delta,F,s)/\partial g_i = 0$, then $MAP_{i,s}$ has the same value for all s, and is equal to $GCV_i(\delta,\phi)$, option price. Thus, if budgetary costs are zero, $F = \phi$, and neither the presence of the resource nor the payment (or receipt) of compensation affects individual government revenues, then option price accurately measures the value of the resource.

A second special case where option price is an appropriate measure of value or of benefits is where F differs from ϕ only by a lump sum payment, i.e. $R_i(I_i-g_i,\delta,F,s) = R_i(I_i,\bar{\delta},\phi,s) + f_i$. If the lump sum payment f_i is collected in a utility neutral way, i.e. $V_i(I_i+f_i,\delta,F) = V_i(I_i,\delta,\phi)$, then $MAP_{i,s} = GCV_i(\delta,F) + f_i$ = option price for all s. Thus, Graham's (1981) assertion that option price is the appropriate measure of benefits when the project is financed through sure payments is verified, though it should be noted that the sure payments must be lump sum (i.e. they must impact utility in the same way that a sure hypothetical compensation payment would).

Where option price is not an appropriate measure, we are faced with new difficulties in estimation of MAP_i. The distinction must be made between the amount that an individual will actually pay towards the costs of the project, $R_i(I_i-GCV_i,\delta,F,s) - R_i(I_i,\bar{\delta},\phi,s)$, and the additional amount the individual would be willing to pay, $GCV_i(\delta,F)$. Estimation of the first amount is a problem of revenue projection. A recent example this type of revenue projection is that of R.M. Adams et al. (1989) who projected revenues generated by various alternative methods of financing a pheasant propagation and management program in Oregon[8]. For estimation of the second amount, $GCV_i(\delta, F)$, the usual valuation methods (travel cost, hedonic pricing, contingent valuation) must be adapted to include explicit consideration of the financing method that will be used.

The relationship between project financing considerations and so-called vehicle bias in contingent valuation surveys should also be noted. It has been observed that choice of the payment vehicle can have an effect on stated willingness-to-pay. For example, an individual might be willing to pay more for preservation of an amenity through user fees than through property taxes (for a review of vehicle bias see Ronald Cummings, David Brookshire, and William Schulze 1986, pages 31-33). Given our discussion here, it is perfectly reasonable that the amount that an individual would be willing to pay for the resource would depend on how that amount would be paid. Indeed, MAP_i should be different for different financing methods. Recall, however, that GCV_i is a lump sum payment. If some vehicle other than a lump sum payment is used to estimate GCV_i in a contingent value survey, then vehicle bias may still be a problem.

Conclusions

The consensus regarding benefit measures under uncertainty that was identified at the beginning of this paper has been shown to have some basis. If a project is financed using state-independent compensation payments, then option price is a correct measure of benefits. If the project is financed

[8] Adams et al. did not, however, consider the potential impacts of compensation on revenues.

using state-dependent payments located on individual willingness-to-pay loci, then the willingness-to-pay locus may be appropriate. Both of these measures can be viewed as special cases of the use of maximum agreeable payment as a benefit measure. In the more realistic situation where the project is financed using something other than lump sum compensation payments, neither option price nor the willingness-to-pay locus is the appropriate measure of benefits. MAP_i is the generally correct measure.

Both option price and MAP_i assume state-independent hypothetical payments. There are, however, two important differences between them. First, MAP_i measures the benefits of a more completely described project. Absent consideration of how the project will actually be paid for, and how that method of financing will affect individual utility, the project is incompletely specified. It matters how a project is paid for, and the benefit measure used to evaluate a project should account for how the financing method to be used. Second, MAP_i includes the revenue effect of hypothetical compensation. This technical adjustment assures that a potential Pareto improvement could be turned into an actual Pareto improvement through lump sum transfers.

Perhaps the most significant implication of this discussion is that there is an important role for economists to play in project design. Proper design of the financing method may be as important or more important than proper design of the size and shape of the project. To this end, the willingness-to-pay locus may suggest financing methods that improve the allocation of risk among individuals. However, MAP_i is the correct benefit measure for evaluating alternative financing methods, and provides a means of choosing among them.

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HICKSIAN VALUES OF UNPRICED QUALITY:

SOUTHWESTERN FISHING

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HICKSIAN VALUES OF UNPRICED QUALITY:

SOUTHWESTERN FISHING

Frank A. Ward and Ibrahim Isytar

Abstract

A marginal benefits function defined over environmental characteristics is specified to be consistent with a flexible form utility index. The system of ordinary demands derived from the utility index is estimated from observed data. Results from southwestern reservoirs reveal recreational values of water that range from $130 to $6,500 per acre foot.

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HICKSIAN VALUES OF UNPRICED QUALITY: SOUTHWESTERN FISHING

INTRODUCTION

A public resource manager faces the challenge of serving its constituency of resource users by selecting packages of policies which maximize the total value of the resource. Benefits that result from policy changes differ markedly at the various site locations and over numerous site characteristics. However, past methodological problems associated with estimating welfare values for unpriced environmental characteristics has made it difficult to determine which sites and site characteristics should receive limited management resources.

Maler (1974), Freeman (1979), Feenberg and Mills (1980), Bradford and Hildebrandt (1977), and others have established the importance of theoretically valid demand systems as a basis for exact welfare measurement. Along these lines, Willig (1976, 1977) derived bounds for the difference between the Marshallian welfare approximations and the theoretically correct Hicksian measures that which result from single and multiple price changes. Hausman (1981) and Morey (1984) derived the unobserved compensated demand function based on observed demands for the case where prices change.

The theoretical framework of a good's characteristics as a source of utility was developed by Gorman (1956) and refined by Lancaster (1966). Morey (1981) established a model of demands for goods which are differentiated by their quality characteristics. More recently, Deaton (1988) developed a method to estimate price elasticities when quantities demanded depend on the opportunity to substitute quality for price.

Additionally, there is a large theoretical and empirical literature on implicit prices, shadow prices, user costs, hedonic indices, and the like. Nonetheless we are unaware of any work which has established methods for estimating a value possibilities surface, defined over numerous dimensions of unpriced quality and based on observable behavior. Lacking a solution to that essential valuation problem results in little basis in economic theory for regulating, managing, or otherwise allocating natural environments or other investments in unpriced quality to their highest valued use.

This paper describes a method for specifying a theoretically correct welfare function defined over changes in complex packages of unpriced quality and which can be estimated from observable demands. Additionally we illustrate application of the method to the problem of valuing complex packages of sportsfishing opportunities in New Mexico.

THEORETICAL MODEL

The expenditure function used for the present study is based on a constrained maximization of a flexible form utility function. The utility function is a second order Taylor's approximation to any underlying utility index in priced quantities, unpriced qualities, and resource user characteristics. Described in more detail in Cole et. al. (1989), the function is:

1) $$\text{Max } U = \boldsymbol{\alpha}'_{XQZ}\mathbf{X} + .5\mathbf{X}'\boldsymbol{\beta}_{XX}\mathbf{X}$$
$$\text{subject to } \mathbf{P}'\mathbf{X} = M$$

$$\text{where: } \boldsymbol{\alpha}_{XQZ} = \boldsymbol{\alpha}_X + \boldsymbol{\beta}'_{XQ}\mathbf{Q} + \boldsymbol{\beta}'_{XZ}\mathbf{Z}$$

and **X** is a vector of annual trips to the *n* sites, represented as average trips per angler from each county zone of origin. **P** is vector of *n* prices representing travel cost; M is a expenditure allocated to environmental goods consumption; **Q**, a vector of site quality attributes including surface area and fish biomass for each of two sites, defined as (1) the "site in question" and (2) "a composite of substitute sites"; **Z** is a vector of resource user characteristics. **Q** is an *mn* x 1 vector which contains *m* unpriced characteristics for each of the *n* sites which are managed by the agency; **Z** is a vector of "other" exogenous utility function shifters, such as demographic indices, and recreational tastes; $\boldsymbol{\alpha}_X$ = vector of linear first order marginal utilities of each of the elements in **X**. $\boldsymbol{\beta}_{XX}$ is *n* x *n* symmetric matrix of coefficients for squares and cross products of X_iX_j. Strict concavity of the utility index requires the main–diagonal terms of the $\boldsymbol{\beta}_{XX}$ to be negative. Off–diagonal terms, can be positive indicating complementarity between any (i,j) pair of goods' quantities, negative, indicating substitutability, or zero, indicating independence.

Maximizing (1) subject to the budget constraint reveals the system of ordinary demands:

$$(2) \qquad \mathbf{X}^* = \{\beta_{\mathbf{XX}}^{-1}\mathbf{P}(\mathbf{P}'\beta_{\mathbf{XX}}^{-1}\mathbf{P})^{-1}[\mathbf{P}'\beta_{\mathbf{XX}}^{-1}(\alpha_{\mathbf{XQZ}}) + \mathrm{M}]\} - \beta_{\mathbf{XX}}^{-1}(\alpha_{\mathbf{XQZ}})$$

The demand system (2) can be estimated from observed data on **P**, **X**, and M . Estimating (2) yields the parameters in the $\alpha_{\mathbf{XQZ}}$ vector and $\beta_{\mathbf{XX}}^{-1}$ matrix elements, and through inversion of $\beta_{\mathbf{XX}}^{-1}$, the matrix $\beta_{\mathbf{XX}}$ is obtained.

Substituting equation (2) into the original utility index (1) produces the indirect utility function $U^o(\mathbf{P}^o, \mathbf{Q}^o, \mathbf{Z}^o, M)$, and through inversion of $U^o(.)$ the expenditure function

$$(3) \qquad E = E(U^o(.); \mathbf{P}, \mathbf{Q}, \mathbf{Z})$$

is recovered, where E is the minimum expenditure required to meet a pre–policy level of utility, $U^o(.)$. It permits the establishment of the theoretically correct Hicksian welfare value which is associated with changes in multiple goods' unpriced quality characteristics.

A major contribution of this paper is the specification and estimation of an exact expression for the marginal benefit (implicit price) function, $\partial E/\partial \mathbf{Q}$, for each of m quality changes at each of n sites. $\partial E/\partial \mathbf{Q}$ is the incremental annual savings in typical resource user's expenditure needed to maintain original welfare per unit increase in any one of the **Q** variables.

METHODOLOGY

Overview

We establish the marginal benefits schedule by obtaining an analytical equation for the gradient of the expenditure function with respect to each of the unpriced quality characteristics. The expression provides the theoretically correct implicit price for several dimensions of unpriced quality at numerous locations. This facilitates a direct marginal benefit comparison to marginal costs of providing the quality improvement.

For this study, the marginal benefits schedule is obtained by differentiating the expenditure function with respect to two dimensions of site quality at each of eight major fishing sites in New Mexico. Fishing sites selected include Abiquiu Reservoir, Bluewater Lake, Caballo Reservoir, Cochiti Reservoir, Elephant Butte Reservoir, Fenton Reservoir, Heron Reservoir, and El Vado Reservoir (Figure 1). The two quality variables used are acre feet of water allocated to fishing to offset evaporative losses and fish biomass density.

Demand Model

The demand model below estimates trips per capita from each zone (county in New Mexico) to each ith reservoir, i = 1...8, and to the substitute site for the ith reservoir (all other sites combined). The demand system for two "generic" sites so described is:

$$(4) \quad \underset{(2\times1)}{\mathbf{X}^{*}} = \{ \underset{(2\times2)}{\beta_{\mathbf{XX}}^{-1}} \underset{(2\times1)}{\mathbf{P}} (\underset{(1\times2)}{\mathbf{P}'} \underset{(2\times2)}{\beta_{\mathbf{XX}}^{-1}} \underset{(2\times1)}{\mathbf{P}})^{-1} [\underset{(1\times2)}{\mathbf{P}'} \underset{(2\times2)}{\beta_{\mathbf{XX}}^{-1}} \underset{(2\times1)}{(\alpha_{\mathbf{XQZ}})} + \mathrm{M}] \} - \underset{(2\times2)}{\beta_{\mathbf{XX}}^{-1}} \underset{(2\times1)}{(\alpha_{\mathbf{XQZ}})}$$

where:

$$(4a) \quad \alpha_{\mathbf{XQZ}} = \alpha_{\mathbf{X}} + \beta_{\mathbf{XQ}}' \mathbf{Q} + \beta_{\mathbf{XZ}}' \mathbf{Z}$$

Thus the demand system (4) predicts visitation to sites based solely on their characteristics. By predicting trips to sites using a shifting frame of reference, the site in question and its substitute can be redefined for repeated application.

There are two reasons for specifying demand in this unusual manner. First, a minimum of two goods are required to specify a system of demands consistent with utility theory and a budget constraint. Furthermore the two equation approach has a desirable property of expandability as it can be applied to any number of sites in a system of recreation sites.[1]

[1]The first element in the 2x1 vector $\mathbf{X}^{*}$ in (4) is a zone's trips to each ith site. The second element in $\mathbf{X}^{*}$ is demand for the substitute composite.

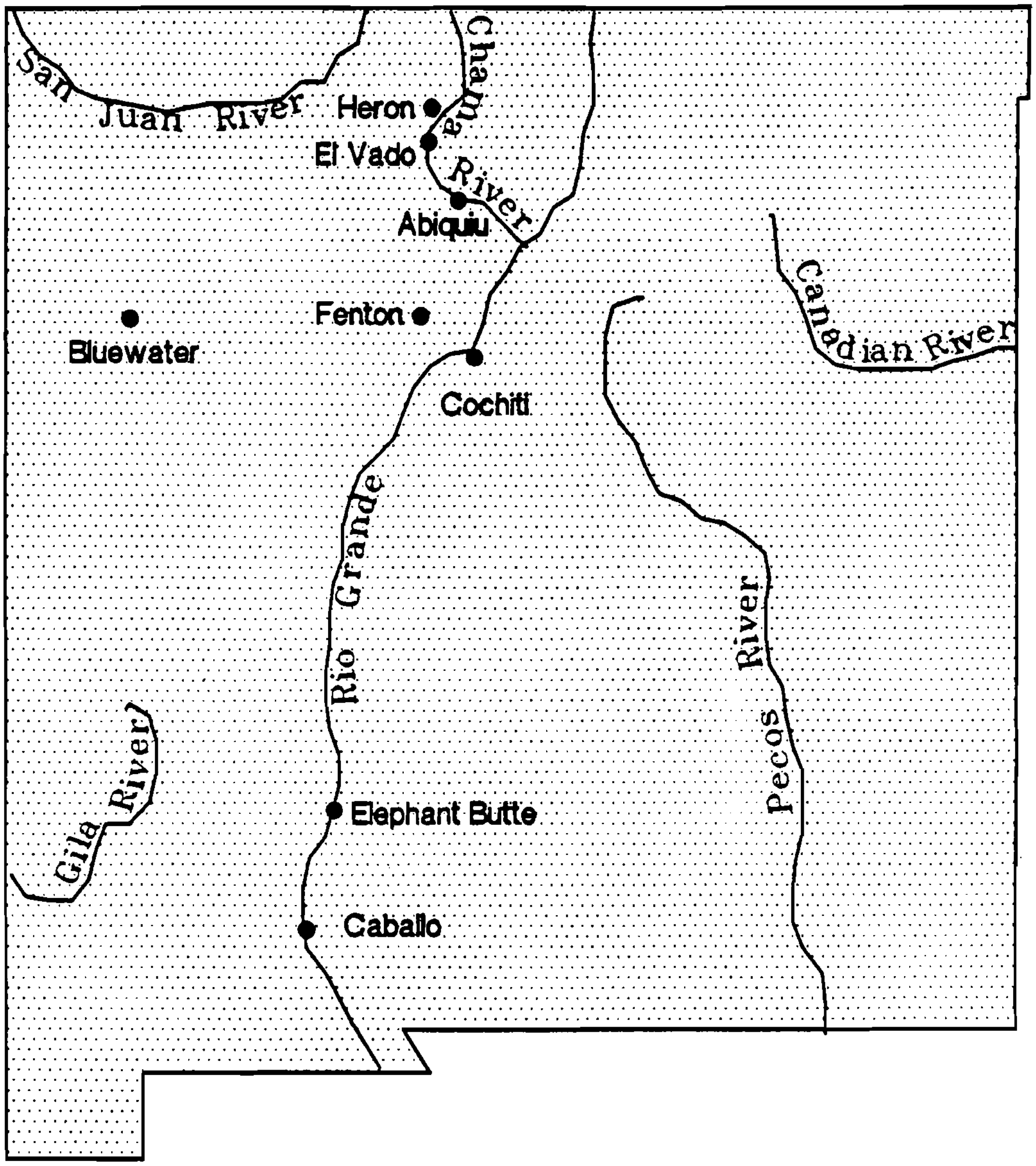

Figure 1: Location of Selected New Mexico Fishing Waters

The system of demand equations (1) was estimated using nonlinear least squares regression (Appendix). Data were obtained form monthly telephone survey data from 1410 anglers sampled in 14 New Mexico counties throughout 1988. The regression model was developed using 112 weighted observations from the surveys. Observations constituted average angler participation rates, travel costs from counties to each of the eight sites, the site quality variables of water contents and fish density, and selected angler characteristics.

Total Benefits

The compensating variation measure of total benefits is defined as:

$$(5) \quad TB = M - E(U^{\circ};\mathbf{P},\mathbf{Q},\mathbf{Z})$$

for the scalars TB, M, and E, and U°, where: the expenditure function E is:

$$(5a) \quad E(U^{\circ};\mathbf{P},\mathbf{Q},\mathbf{Z}) = \frac{-b+[\,b^{2}-4\,a\,c\,]^{.5}}{2\,a}$$

The terms in (5a) are defined below as:

$$(5b) \quad a = .5\,\mathbf{T}_2'\boldsymbol{\beta}_{\mathbf{XX}}\mathbf{T}_2$$

$$(5c) \quad b = .5\,\mathbf{T}_1'\boldsymbol{\beta}_{\mathbf{XX}}\mathbf{T}_2 + \mathbf{T}_2'\boldsymbol{\beta}_{\mathbf{XX}}\mathbf{T}_1 + \boldsymbol{\alpha}'_{\mathbf{XQZ}}\mathbf{T}_2$$

$$(5d) \quad c = .5\,\mathbf{T}_1'\boldsymbol{\beta}_{\mathbf{XX}}\mathbf{T}_1 + \boldsymbol{\alpha}'_{\mathbf{XQZ}}\,\mathbf{T}_1 - U^{\circ}(\cdot)$$

where: $U^{\circ}(.)$ is the value of the indirect utility function at observed pre–policy conditions, $\mathbf{P}^{\circ}$, $\mathbf{Q}^{\circ}$, $\mathbf{Z}^{\circ}$, and M. The remaining variables in (5) are:

(5e) $$T_1 = -\beta_{XX}^{-1}\left[I - P(P'\beta_{XX}^{-1}P)^{-1}P'\beta_{XX}^{-1}\right]\alpha_{XQZ}$$

(5f) $$T_2 = \beta_{XX}^{-1}P(P'\beta_{XX}^{-1}P)^{-1}$$

I is the identity matrix, and all other terms are defined previously. Derivations are provided in Cole et. al. (1989). For any given quality change from $\mathbf{Q}^{o}$ to $\mathbf{Q}$ at any site or its substitute, there is a unique total benefit for each zone of origin.

Marginal Benefits of Unpriced Quality

The following is an analytical expression for the marginal benefit function, based on the expenditure function defined in equations (5). The marginal benefit expression for each of three quality characteristics of the eight sites, $\partial E/\partial \mathbf{Q}$, is found through use of the chain rule for differentiation:

(6) $$\underset{(1\times3)}{\frac{\partial E}{\partial \mathbf{Q}}} = \underset{(1\times1)}{\frac{\partial E}{\partial b}}\left[\underset{(1\times2)}{\frac{\partial b}{\partial \mathbf{T}_1}}\ \underset{(2\times3)}{\frac{\partial \mathbf{T}_1}{\partial \mathbf{Q}}} + \underset{(1\times3)}{\frac{\partial b}{\partial \mathbf{Q}}}\right] + \underset{(1\times1)}{\frac{\partial E}{\partial c}}\left[\underset{(1\times2)}{\frac{\partial c}{\partial \mathbf{T}_1}}\ \underset{(2\times3)}{\frac{\partial \mathbf{T}_1}{\partial \mathbf{Q}}} + \underset{(1\times3)}{\frac{\partial c}{\partial \mathbf{Q}}}\right]$$

where E is minimum annual expenditure on fishing trips necessary to maintain the pre–policy of utility for the typical New Mexico angler, from a given with angler characteristics defined by Z.

The following equations are used to implement the marginal benefits expression (6). They are obtained by taking partial derivative of the terms in expenditure function as defined in (6) and substituting at the appropriate points in equations (5a) – (5f).

(6a) $$\underset{(1\times1)}{\frac{\partial E}{\partial b}} = \frac{-1 + .5\,[\,b^2 - 4ac\,]^{-.5}\,2b}{2c}$$

(6b) $$\underset{(1\times2)}{\frac{\partial b}{\partial \mathbf{T}_1}} = \underset{(1\times2)(2\times2)}{.5\mathbf{T}_2'\beta_{XX}} + \underset{(1\times2)(2\times2)}{\mathbf{T}_2'\beta_{XX}}$$

(6c) $$\underset{(2\times 3)}{\frac{\partial \mathbf{T}_1}{\partial \mathbf{Q}}} = -\underset{(2\times 2)}{\beta_{\mathbf{XX}}^{-1}}\left[\underset{(2\times 2)}{\mathbf{I}} - \underset{(2\times 1)}{\mathbf{P}}\,(\underset{(1\times 2)}{\mathbf{P}'}\,\underset{(2\times 2)}{\beta_{\mathbf{XX}}^{-1}}\,\underset{(2\times 1)}{\mathbf{P}})^{-1}\,\underset{(1\times 2)}{\mathbf{P}'}\,\underset{(2\times 2)}{\beta_{\mathbf{XX}}^{-1}}\right]\underset{(2\times 2)}{\beta'_{\mathbf{XQ}}}$$

(6d) $$\underset{(1\times 3)}{\frac{\partial b}{\partial \mathbf{Q}}} = \underset{(1\times 2)}{\mathbf{T}'_2}\,\underset{(2\times 3)}{\beta'_{\mathbf{XQ}}}$$

(6e) $$\underset{(1\times 1)}{\frac{\partial \mathrm{E}}{\partial c}} = \frac{.5\,[\,b^2 - 4\,a\,c\,]^{-.5}\,(-4\,a)}{2\,a}$$

(6f) $$\underset{(1\times 1)}{\frac{\partial c}{\partial \mathbf{T}_1}} = \underset{(1\times 2)}{\mathbf{T}'_1}\,\underset{(2\times 2)}{\beta_{\mathbf{XX}}} + \underset{(1\times 2)}{\alpha'_{\mathbf{XQZ}}}$$

(6g) $$\underset{(1\times 3)}{\frac{\partial c}{\partial \mathbf{Q}}} = \underset{(1\times 2)}{\mathbf{T}'_1}\,\underset{(2\times 3)}{\beta'_{\mathbf{XQ}}}$$

Using (6a) – (6g), a program was written to obtain numeric values of marginal benefits of the water and fish biomass for the eight "own sites" and water at the substitute site. The two own site quality variables are transformed in order to preserve diminishing marginal utility function in the original quality variables.[2] Because a primary cost of water allocated to fishing in the arid west is evaporation losses, we converted the marginal values of surface areas of water into values per unit volume of water evaporated.[3]

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[2]To obtain values of marginal benefit of each quality dimension, marginal values obtained from (6a) – (6g) were multiplied by the derivatives of transformed surface acre of water ($Q_1^{.5}$). Marginal values were computed with respect to surface acre of water $[\partial E/\partial Q_1^{.5}]\,[\partial Q_1^{.5}/\partial A_1]$ and fish biomass (B) $\partial E/\partial B = [\partial E/\partial Q_2^{.5}]\,[\partial Q_2^{.5}/\partial B]$.

[3]Converting values per acres exposed to values of volume evaporated was done by:

$$\frac{\partial \mathrm{E}}{\partial \mathbf{V}} = \frac{\partial \mathrm{E}/\partial \mathbf{A}}{\partial \mathbf{V}/\partial \mathbf{A}}$$

where: $\mathbf{V}$ = volume evaporated, $\mathbf{A}$ = surface acres of water, and $\partial\mathbf{V}/\partial\mathbf{A}$ = additional annual evaporation per surface acre exposed; $\partial E/\partial \mathbf{A}$, the marginal benefit of fishing from an incremental surface acre.

RESULTS

Value of Additional Water

Results show marginal recreational fishing benefit per incremental acre foot of water consumed for fishing and marginal benefits from incremental fish biomass density. Benefits are summed over all statewide anglers. Table 1 shows aggregate marginal benefit to New Mexico anglers by zone and site as a result of improved opportunities for fishing from incremental fishable water other things equal. For any given *zone*, the *site* with closer water, higher overall site quality, better fishing, smaller reservoirs, and lower evaporation all contribute to higher marginal values per acre foot of water delivered to the site. By contrast, for any given *site*, those *zones* which receive the highest marginal benefit from that site are those which are closest to the water, and which have fewest substitute opportunities for fishing.

Results of table 1 reveal highest aggregate marginal benefit of water for Bernalillo County anglers at Fenton Lake. This relatively high value of water occurs because Fenton Lake is small, has low evaporation, good fishing, and it is closer than any of the other seven sites to the state's population center at Albuquerque. The next highest aggregate marginal benefit is produced by Bluewater Lake. Although Bluewater is considerably more popular than Fenton in absolute attractive power it has 50 times more surface area; therefore the value of water per additional unit of volume delivered is much less at Bluewater Lake.

Value of Additional Fish

Table 2 describes aggregate marginal values to anglers by zone and site as a result of policies that increase fish density. From a given zone, closer water, higher site quality, better fishing, small water, and lower evaporation rate all contribute to higher marginal values of an additional kg/ha of fish density. For any site, zones which receive the highest marginal benefit from water are located closest to the water have few substitute opportunities.

Findings in Table 2 have considerable policy implications for western fisheries managers since planted fish may be more cheaply available or otherwise exhibit fewer constraints as a

Table 1. Marginal Fishing Benefit Per Additional Acre Foot of Water at Selected New Mexico Reservoirs, 1988.

New Mexico County (Zone of Origin)	Total Angler Population (1000's)	Reservoirs							
		Abiquiu	Blue Water	Caballo	Cochiti	Elephant Butte	Fenton	Heron	Elvado
		dollars per acre foot per year							
Bernalillo	52.3	257	898	78	462	63	5,013	391	389
Cibola	4.2	1	193	1	8	1	53	4	1
Dona Ana	11.6	0	0	35	0	15	0	0	0
Hidalgo	1.6	0	16	7	3	11	0	7	0
Los Alamos	2.6	74	40	7	29	4	383	24	41
McKinley	3.7	1	60	3	10	1	102	7	2
Otero	5.3	0	1	19	0	10	0	7	0
Rio Arriba	2.1	51	53	10	37	4	484	48	55
Sandoval	4.2	36	24	5	40	3	352	20	17
Sierra	1.1	0	0	0	0	12	0	0	0
Santa Fe	7.4	0	15	0	105	2	99	45	27
Socorro	.5	0	0	0	0	4	0	0	0
Taos	2.6	0	0	0	2	0	0	97	0
Valencia	3.7	26	36	4	30	4	49	10	0
TOTAL	***103.0***	***447***	***1,336***	***170***	***728***	***133***	***6,536***	***660***	***531***

Table 2. Marginal Fishing Benefit Per Unit* Change in Fish Density at Selected New Mexico Reservoirs, 1988.

New Mexico County (Zone of Origin)	Total Angler Population (1000's)	Reservoirs							
		Abiquiu	Blue Water	Caballo	Cochiti	Elephant Butte	Fenton	Heron	Elvado
		dollar/year							
Bernalillo	52.3	8,580	10,470	6,250	14,220	9,810	12,080	10,990	10,480
Cibola	4.2	40	2,250	40	260	80	130	120	30
Dona Ana	11.6	0	0	2,800	0	2,270	0	0	0
Hidalgo	1.6	0	180	570	100	1,750	0	180	0
Los Alamos	2.6	2,480	470	540	900	600	920	670	1,120
McKinley	3.7	50	700	270	320	210	250	190	40
Otero	5.3	0	10	1,560	0	1,580	0	190	0
Rio Arriba	2.1	1,700	620	800	1,140	690	1,170	1,350	0
Sandoval	4.2	1,200	280	440	1,220	500	850	550	450
Sierra	1.1	0	0	0	0	1,790	0	0	0
Santa Fe	7.4	0	170	0	3,220	260	240	1,280	0
Socorro	.5	0	0	10	0	590	0	0	0
Taos	2.6	0	0	0	80	0	0	2,730	0
Valencia	3.7	880	420	360	930	620	120	280	0
TOTAL	***103.0***	***14,930***	***15,580***	***13,620***	***22,380***	***20,740***	***15,750***	***18,520***	***12,120***

*Units are kg/ha; benefits rounded to nearest $10.

manageable resource than water supply. In the arid southwest, fishable water is usually dependent on weather, season, competing demands, and prior water rights.

For any two counties with equal angler populations, the closest one to a fishing site will derive the higher benefit from its presence. For instance, comparing marginal values of Bluewater Lake for McKinley and Valencia counties show about the same angler population; however Bluewater Lake provides McKinley County anglers with an annual marginal benefit of about $700/kg–ha with only about $400 provided to Valencia county anglers. In summary findings suggest that the larger part of potential recreation benefits are likely to be concentrated in a few select sites that are accessible to large population centers and over quality dimensions that consume the fewest management resources.

CONCLUSIONS

A unique contribution of this research is the derivation of an analytical marginal benefits schedule that results from changes in unpriced environmental characteristics. This is accomplished by obtaining an expression for derivative of an empirically estimated expenditure function with respect to fishing quality characteristics. Because the estimated demand and expenditure functions are consistent with an underlying utility index, the result provides the theoretically correct marginal benefits function for each of several dimensions of environmental quality.

Since the method developed in this study estimates only marginal benefit and not marginal cost, knowledge of marginal cost of the environmental characteristics is required to use the method to maximize resource user benefits. Nevertheless obtaining marginal benefits from observed data on environmental improvements has historically posed considerable problems in methodology and concept. Hence our methods provide a small but significant step in the quest for economically efficient environmental management.

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APPENDIX

Described more fully in (Cole, et al. 1989), the estimation yielded the following values of parameters and variables described in (1) – (1a).

(A1) $$\alpha_{\mathbf{X}} = \begin{bmatrix} -51.34972 \\ 1 \end{bmatrix}$$

(A2) $$\beta^{-1}_{\mathbf{XX}} = \begin{bmatrix} -0.96256 & -3.61037 \\ -3.61037 & -17.3050 \end{bmatrix}$$

(A3) $$\beta'_{\mathbf{XQ}} = \begin{bmatrix} 0.06073 & 0.3295 & 0 \\ 0 & 0 & 0.00469852 \end{bmatrix}$$

(A4) $$\beta'_{\mathbf{XZ}} = \begin{bmatrix} 18.7712 & 37.0904 & 42.8294 & 0.02607 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

(A5) $$\mathbf{P} = \begin{bmatrix} P_1 \\ P_2 \end{bmatrix} = \begin{bmatrix} \text{site price, for each zone and site} \\ \text{substitute price for the site in question for each zone and site.} \end{bmatrix}$$

The site price vector, **P** is the independent variable, the distance from any zone to a site in miles multiplied by a total variable cost of $0.35/ mile, and substitute price is the average distance of all substitute sites, weighted by the number of trips taken to the substitute sites. Additionally the following variables are defined:

(A6) M = expenditure, a scalar, equal to the sum of prices times quantities, constant for each zone.

$$\text{(A6)} \quad \mathbf{Q} = \begin{bmatrix} (Q_1)^{.5} \\ (Q_2)^{.5} \\ (Q_3) \end{bmatrix}$$

Q_1 is the size of the reservoir measured by the average number of surface acres of water during the summer months. Q_2 is the quality of fishing measured by biomass density in kg/ha of game fish. Square roots were used to account for diminishing marginal utility from additional water and fish biomass. Q_3 is the average fishing quality at the substitute site, measured as average biomass available at substitute sites.

Angler characteristics are defined as:

$$\text{(A7)} \quad \mathbf{Z} = \begin{bmatrix} (Z_1) \\ (Z_2) \\ (Z_3) \\ (Z_4) \end{bmatrix}$$

where Z_1 is a dummy variable, assigned a 1 if $P_1 \leq 35$, and a 0 otherwise. Z_2 is assigned a 1 if $P_1 \leq 15$, and 0 otherwise. These variables account for theoretically expected heavy visitation from zones to especially nearby sites. Z_3 is a dummy variable, assigned a 0 if $P_2 \leq 15$. This variable accounts for theoretically expected light visitation from zones to sites that are farther away than especially nearby sites. Z_4 is a proxy for angler commitment to fishing, at a particular site, measured the amount spent in dollars per year on fishing equipment.

WELFARE EFFECTS OF CHANGES IN QUALITY: A SYNTHESIS

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WELFARE EFFECTS OF CHANGES IN QUALITY: A SYNTHESIS

N.E. Bockstael and K.E. McConnell

Abstract

Changes in public goods can frequently be modeled as changes in qualities for models of consumer preferences with quality-differentiated goods. Measurement of the benefits of changes in the quality of a good can then be used as a vehicle for measuring the benefits of changes in public goods. Welfare measurement for changes in the quality of goods is not as well established as for price changes. We show the theory of welfare measurement for changes in the quality of goods which provides a basis for measurement using observations on individual behavior. We analyze the empirical implications of weak complementarity and nonessentiality, two properties which are critical in welfare measurement.

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Welfare Effects of Changes in Quality:

A Synthesis

A significant challenge facing economists involves the measurement of changes in the quality of goods and services. Benefit-cost analyses of public actions are often best construed as studies of the qualities of private goods induced by changes in public goods. Frequently, benefit-cost analysis of a resource change leads to an analysis of a dimension of the quality of the resource, such as visibility, water pollution, fish catch, hunter's bag, etc., which is simultaneously a quality characteristic of a privately consumed good.

The degree to which a market separates public actions from private consumption decisions is critical to the analysis of the welfare effects of quality changes. The familiar hedonic model is appropriate when public actions change the quality of a good which is traded on a market. For many public goods, especially environmental goods, this is not the case; public actions induce quality changes in the absence of a market. We address this case with the use of a quality-differentiated goods model, where the quality characteristics of each good are determined exogenously and, at least in part, by public actions. The quality-differentiated goods model is of interest to economists broadly, but has an immediate relevance for resource economics. It is the basis for valuing changes in environmental amenities using recreational demand (and more narrowly, travel cost) models. For example, studies such as Smith and Desvousges, Caulkins, Bishop and Bouwes, and Feenberg and Mills implicitly rely on this model.

A consistent theory of welfare measurement for changes in the quality of goods has not come easy. Economists think of welfare measures as synonymous with areas under demand curves, a correspondence well established for the welfare effects of price changes. However, the absence of a similar easy correspondence for quality changes has lead to confusion in the literature on the measurement of these welfare effects.

Many of the components necessary for the welfare theory of quality changes have been worked out elsewhere in different settings (see Willig, Bradford and Hildebrandt, Maler, Freeman, Hanemann). A coherent story of welfare measurement of exogenous quality changes remains to be told. In this paper, our purpose is to tell this story and interpret its relevance for applied work. In telling the story, we show that exact parallels do not exist between the welfare theory of price and quality changes. In general, commonly accepted results for price changes can be established for quality changes only with more stringent restrictions. Of particular interest is the relationship between the compensating and equivalent variation and the ordinary surplus of a quality change, which we explore in later sections. Further, we develop the empirical implications of weak complementarity, the key concept in welfare measurement for quality changes.

Why Price Changes Are "Easy" and Quality Changes Are Not

Price provides a unique link between observable behavior and welfare measurement because of its role in the decision problem. The fundamentals of welfare measurement depend on Shepherd's Lemma. Simply stated, the standard money measures of welfare change are defined as changes in the expenditure function, changes in the amount of money needed to achieve a given utility level. The compensated (or Hicksian) demand function is the marginal change in the expenditure function with a change in price. Therefore, integrating the compensated demand over a price range gives the change in the expenditure function and provides a welfare measure of that price change. Stated mathematically,

$$(1) \qquad CV = m(p_i^0,\bar{p}^0,u^0) - m(p_i^1,\bar{p}^0,u^0) = \int_{p_i^1}^{p_i^0} \frac{\partial m}{\partial p_i}\,dp_i = \int_{p_i^1}^{p_i^0} g^i(p,u)\,dp_i$$

where CV is compensating variation, p_i is the price of the i^{th} good, $\bar{p}$ is the price vector of all other goods, $m(p,u)$ is the expenditure function, and $g^i(p,u)$ is the compensated demand function for the i^{th} good.

This principle has also provided the basis for assessing the broader question of value of access to a good. When the upper bound on the price change is high enough to cause demand to fall to zero, then the price change is analogous to eliminating the good. Denoting this "choke" price as $\bar{p}_i$, the measure

$$CV = \int_{\bar{p}_i}^{p_i^0} \frac{\partial m}{\partial p_i}\,dp_i = \int_{\bar{p}_i}^{p_i^0} g^i(p,u)\,dp_i$$

equals the entire area under the compensated demand above current price. This measure(actually, its absolute value) has frequently been used to value the existence of a good or access to a resource.

The equivalences in (1) beg the question somewhat. Usually observable behavior does not coincide with compensated demand. We see the behavior implied by ordinary (i.e. Marshallian) demand, and we measure the integral of the ordinary demand function. Yet results connecting the compensated and ordinary demands exist as well. First, if the income elasticity of the good is zero, then the compensated and ordinary demands coincide. Even if this condition does not hold, the consumer surplus of a price change, i.e. the integral of the ordinary demand function over a range of prices, falls between the compensating and equivalent variation of that price change. Willig has shown that information about consumer surplus and the size of the income effect can provide bounds on the variational measures.[1]

These positive theoretical results for price changes have encouraged similar analyses for quality changes, but in the quality case the fundamental property is absent. There is no counterpart to Shepherd's Lemma here. Designating the quality of good x as b, there exists no behavioral function which equals $\partial m/\partial b$. There is no behavioral function which we can first estimate and then integrate over a range of b to give the expenditure function.

In this paper we address two questions. First, if compensated demand functions were observed, could we derive meaningful measures of the welfare change associated with a quality change? Second, given that we can only acquire information about Marshallian functions, would this information allow us to obtain approximations for compensating and equivalent variation measures?

<u>When We Know the Compensated Demand Function</u>

We begin with the individual's decision problem:

$$\max_{x} u(x,b) + \lambda(y - p'x). \tag{2}$$

In the general case, x is a vector of goods, p is a corresponding vector of prices, b is a matrix of quality characteristics associated with the goods, y is income, and λ is a Lagrangian multiplier. In many applications of resource economics, market prices for the goods of interest do not exist, in which case the p's associated with non-market goods represent constant marginal costs of these goods and are treated as parametric prices.

The cost minimization problem associated with (2) is

$$\min p'x + \mu(u - u(x,b)),$$

which includes in its solution the compensated demands,

$$x = g(p,b,u).$$

Substituting compensating demands into the minimization problem gives the expenditure function m(p,b,u) where

$$(3) \qquad m(p,b,v(p,b,y)) = y$$

and inversion gives the indirect utility function

$$(4) \qquad v(p,b,m(p,b,u)) = u.$$

The quality characteristics are assumed to enter the preference structure such that $\partial u/\partial b > 0$ which implies $\partial v/\partial b > 0$ and $\partial m/\partial b < 0$.

One aspect of the preference structure demands emphasis. We assume a structure consistent with the quality-differentiated goods model implying that the quality characteristics of interest are attached to goods. A classic example is the original application by Stevens: the good is salmon fishing trips on the Columbia River, and a quality characteristic is the expected catch of salmon on those trips. Examples of other such relations include: trips to a beach, and the secchi disk reading of water quality at the beach; the number of cross-country skiing trips to an area, and the miles of trail available. The quality characteristics are assumed exogenous to the individual and thus appear as parameters in the utility maximization problem. The quality-differentiated goods model with its association between specific characteristics and specific goods, imposes more structure on the preference function than is apparent from the general notation used above.

In this paper, we address the one-good one-quality case. The case in which there are several quality-differentiated goods involves some additional features and is pursued in a companion paper. We solve problem (2) for the specific case when we are interested in one good, x_i, which has quality characteristic b.

The compensating variation measure of the welfare effect of a quality change for good i is defined as

$$(5) \qquad CV(\Delta b) = m(p_i^0, b^0, \bar{p}, u^0) - m(p_i^0, b^1, \bar{p}, u^0)$$

where $\bar{p}$ is a vector of the prices of all other goods.[2] Of course, the expenditure function is not observed, but if we had estimates of the compensated demand function for x_i, could the CV measure in (5) be calculated? The answer is no, at least not in a way analogous to the price change case. Unlike the price change case where $\partial m/\partial p$ fortuitously equals compensated demand, there exists no behavioral function which equals $\partial m/\partial b$.

An alternative is available. Why not compute the value of access to the good in question before and after the change in quality? Specifically, can the compensating variation of a change in quality be measured as

$$(6) \qquad \int_{p^0}^{\bar{p}} g(p, b^1, u)dp - \int_{p^0}^{\bar{p}} g(p, b^0, u)dp \ ?$$

Calculating this change in areas yields

$$(7) \quad m(\bar{p}_i(b^1), \bar{p}, b^1, u) - m(p_i^0, \bar{p}, b^1, u) - m(\bar{p}_i(b^0), \bar{p}, b^0, u) + m(p_i^0, \bar{p}, b^0, u),$$

where $\bar{p}_i(b)$ is the price which drives the optimal x_i to zero. The second and fourth terms together equal the compensating variation of the quality change (expression (5)). Consequently, the change in the area behind the Hicksian demand is the correct measure only if the first and third terms in (7) together equal zero.

Weak complementarity is the property that the expenditure function is independent of b when the price of x is so high that x is not chosen. Weak complementarity implies that the change in the areas in (7) equals compensating variation in (5). Under weak complementarity,

$$m(\tilde{p}_i(b^1), \bar{p}, b^1, u) = m(\tilde{p}_i(b^0), p, b^0, u).$$

There is another way of looking at the problem. The indefinite integral of the compensated demand function yields

$$\int g(p,b,u)dp = e(p,b,u) + c(\cdot)$$

where $e(p,b,u) + c(\cdot) \equiv m(p,b,u)$ and $c(\cdot)$ is the constant of integration which cannot be recovered. This constant poses no problem in assessing price changes. It cannot be a function of price since the integration is over price. Consequently the welfare change associated with a price change can as easily be defined with the $e(\cdot)$ function as with the complete expenditure function:

$$\begin{aligned} m(p^0,u^0) - m(p^1,u^0) &= e(p^0,u^0) + c(\cdot) - e(p^1,u^0) - c(\cdot) \\ &= e(p^0,u^0) - e(p^1,u^0). \end{aligned}$$

However, there is no guarantee that $c(\cdot)$ will not be a function of quality, and if it is, then

$$\begin{aligned} CV(\Delta b) &= m(p^0,b^0,u^0) - m(p^0,b^1,u^0) \\ &= e(p^0,b^0,u^0) - e(p^0,b^1,u^0) + c(b^0) - c(b^1) \\ &\neq e(p^0,b^0,u^0) - e(p^0,b^1,u^0), \end{aligned}$$

the former being the true measure while the latter is the recoverable measure. Consequently, in the general case, $CV(\Delta b)$ cannot necessarily be calculated even with knowledge of the compensated demand function. However, weak complementarity implies that $c(\cdot)$ is not a function of quality so that integrating back from the compensated demand yields the proper measure (Mäler, p. 183-7).

Weak complementarity is the most central concept in benefit-cost analysis. Mäler originally developed the concept to show the circumstances in which changes in the area under compensated demand curves capture the value of a change in a public good. The nature of weak complementarity has been completely characterized by Willig. If b is weakly complementary to x_i, then

(8) $$\left.\frac{\partial u(x,b)}{\partial b}\right|_{x_i=0} = 0 \qquad \text{for all values of } x_j,\ j \neq i.$$

Willig (1978) proves that this condition holds if and only if:

(9) $$\lim_{p_i \to \infty} \frac{\partial v}{\partial b}(p_i, \bar{p}, b, y) = 0,$$

or alternatively

(10) $$\lim_{p_i \to \infty} \frac{\partial m}{\partial b}(p_i, \bar{p}, b, u) = 0,$$

where letting $p_i \to \infty$ means letting p_i go to the limit price. This property, stated in one way or another, is well known. A change in b does not affect an individual's utility if the individual consumes no x_i.

To invoke weak complementarity, we need the condition of nonessentiality. Nonessentiality has been explored in detail by Willig (1978). A good is nonessential if we can find combinations of other goods which will compensate the individual for its absence. If x_1 is nonessential, for example, then there exists a vector of x_j^1's, $j > 1$, such that

(11) $$u(x_1^0, x_2^0, \ldots, x_n^0, b) = u(0, x_2^1, \ldots, x_n^1, b),$$

where the x_i^0's are the utility maximizing demands given a set of prices and income. By the dual characterization to condition (11), x_1 is nonessential <u>if and only if</u> there exist $\bar{p}^1$ and y^1 such that

$$(12) \qquad v(p_1^0, \bar{p}^0, b^0, y^0) = \lim_{t \to \infty} v(t, \bar{p}^1, b^0, y^1),$$

where $t \to \infty$ is shorthand for $t \to p_1^*$, the price that sets the Marshallian demand to zero. (For normal goods, the Marshallian choke price will not exceed the Hicksian choke price, $\tilde{p}$.) Expression (12) implies an equivalent condition for the expenditure function, that the limit of the expenditure function as $p_1 \to \infty$ is finite.

It is clear that a good is nonessential if and only if the area inside its compensated demand curve is finite. The notion of nonessentiality turns on the ability to compensate an individual completely for the loss of access to x, which means that the definition is couched in terms of compensation, not behavior. If the good is nonessential and non-inferior, not only will its compensating variation be finite but its Marshallian consumer surplus will be as well, since the Marshallian demand for non-inferior goods lies everywhere inside the Hicksian demand as price is increased.[3]

We assume nonessentiality--not unreasonable for quality-differentiated goods, each one of which may have many close substitutes, nor for environmental goods, many of which are recreational activities. With this property, the limit of both consumer surplus and compensating variation must be finite.

<u>Measuring the Welfare Effects of Quality Changes Using Marshallian Demands</u>

Even with compensated demand functions, the welfare measurement results of quality changes are not as neat as those for price changes. Intuitive but restrictive assumptions must be imposed on preferences to obtain results. Now, suppose only Marshallian functions are available, as is usually the case. Under what circumstances can we use the change in the area under Marshallian demand curves,

$$(13) \qquad \int_{p^0}^{\infty} x^y(p,b^1,y)dp \;-\; \int_{p^0}^{\infty} x^y(p,b^0,u)dp,$$

as a good approximation of the compensating variation (equation 5)? Once again the quality change results depend on strict assumptions and fall short of those which can be established for price changes.

In the case of one price change or for many price changes if all are in the same direction, CV < CS < EV when the goods are normal. Despite the familiarity of these conditions, deriving them anew provides clues for deriving results in the quality change case. Starting with the identity in (3) and differentiating with respect to price:

$$(14) \qquad m_p(p,v(p,y)) + m_u(p,v(p,y))\, v_p(p,y) = 0.$$

Recognizing that $m_u = 1/v_y$ and rewriting (14) gives

$$(15) \qquad m_p(p,v(p,y)) = \frac{-v_p}{v_y}(p,y)$$

which merely shows that at the point where $m(p,u)=y$, the Hicksian demand (the term on the left) and the Marshallian demand (the term on the right) are equal.

Ultimately we wish to compare $\int m_p dp$ (or equivalently, $\int x^u dp$) with $\int -v_p/v_y dp$ (or, $\int x^y dp$) over a discrete price change. The comparison is facilitated by looking at how x^u and x^y change as we move away from their common point. Further differentiating with respect to p yields

(16) $$m_{pp} + m_{pv}v_p = \partial(-v_p/v_y)/\partial p$$

or, written in a more familiar way,

$$\frac{\partial x^u}{\partial p} - x\,\frac{\partial x^y}{\partial y} = \frac{\partial x^y}{\partial p}$$

which is recognizable as the Slutsky equation. The fact that both $\partial x^u/\partial p$ and $\partial x^y/\partial p$ are negative and that $-x\ \partial x/\partial y$ is negative for a normal good assures that the integral (over a given price range) of x^y will exceed the integral of x^u over the same range, or that CV < CS (when the previously established sign conventions are observed). Similar manipulations prove EV > CS. These results do not require any prior restrictions on preferences except that the good in question be normal. If the good is inferior, CS is still bounded by CV and EV but in the reverse order.

Similar expressions to (14) through (16) can be derived for quality changes, but they depend once again on additional restrictions on preferences. Nonetheless, the method used above to demonstrate the ranking of welfare measures associated with price changes provides a useful template for the analysis of quality changes.

A. The Quality Slope of Consumer Surplus

Starting again with expression (3), differentiate this time with respect to b:

(17) $$m_b(p,b,v(p,b,y)) + m_u(p,b,v(p,b,y))v_b(p,b,y) = 0$$

or

(18) $$-\ m_b(p,b,v(p,b,y)) = \frac{v_b}{v_y}(p,b,y).$$

Expression (18) is remarkably similar to expression (15) from the price change case. At the point where $m(p,b,v(p,b,y)) = y$, the marginal change in the expenditure function with a change in b equals the ratio v_b/v_y.

In the price change case the next step is to compare the functions as we move away from their common point. Such a comparison is relevant because the two functions in (15) have meaningful interpretations: m_p is both the slope of the expenditure function with respect to price and the Hicksian demand, and $-v_p/v_y$ equals the Marshallian demand which in turn is the price slope of consumer surplus. In (18), the left-hand side is obviously the slope of the expenditure function with respect to quality, and its integral over b gives the compensating variation of a change in b. The analogy with the price case would be complete if the right-hand side of (18) were the quality slope of consumer's surplus. Willig (1978) shows that only under certain conditions will the right-hand side of (18) be the quality slope of the area under the Marshallian demand function. Under the Willig requirements, the integral of this slope over the range of b will give the change in consumer's surplus from a change in b. Willig shows that if x is nonessential and x and b are weak complements, then the following equality holds

(19) $$\frac{v_b}{v_y}(p^0) = \int_{p^0}^{\bar{p}} \frac{\partial x^y}{\partial b}\, dp$$

if and only if v_b/v_p is independent of income. Note that the right hand side of (19) is the quality slope of the Marshallian surplus.[4]

The equality in (19) is as close as we get to a fundamental equation of welfare economics for quality changes. As such it is worth examining Willig's condition more closely. To show (19), first note that weak complementarity implies

$$\frac{v_b}{v_y}(\bar{p}) = 0$$

because indirect utility is independent of b when the good in question is not consumed. Using this result and substituting $-v_p/v_y$ for x^y via Roy's Identity means that (19) can be rewritten as

$$(20) \qquad -\frac{v_b}{v_y}(p) + \frac{v_b}{v_y}(p^0) = \int_{p^0}^{\bar{p}} \frac{\partial(-v_p/v_y)}{\partial b} dp.$$

Carrying out the differentiation on the right hand side of (20) yields

$$-\frac{v_b}{v_y}(p) + \frac{v_b}{v_y}(p^0) = \int_{p^0}^{\bar{p}} -\frac{(v_{pb}v_y - v_p v_{yb})}{{v_y}^2} dp.$$

But this simply implies that

$$(21) \qquad \frac{\partial}{\partial p}\left[\frac{v_b}{v_y}\right] = \frac{v_{pb}v_y - v_p v_{yp}}{{v_y}^2}.$$

Completing the differentiation on the left hand side of (21) and equating to the right hand side gives

$$(22) \qquad \frac{v_y v_{bp} - v_b v_{yp}}{{v_y}^2} = \frac{v_y v_{pb} - v_p v_{yb}}{{v_y}^2}.$$

Expressions (19) and (22) are mathematically equivalent; if one holds the other does also. Clearly (22) holds if

$$v_{by}\ v_p = v_{py}\ v_b.$$

A necessary and sufficient condition for this is

$$(23) \qquad \frac{\partial(v_b/v_p)}{\partial y} = 0.$$

Thus the right-hand side of (18) is the slope of consumer's surplus if

$\partial(v_b/v_p)/\partial y = 0$. (See Willig, pp. 241-244.)

We have shown that the quality slope of the expenditure function equals the quality slope of the consumer's surplus function, but only under certain conditions. An equivalent statement of the Willig condition is that a quality induced change in consumer's surplus, averaged over the number of units of the good demanded, be independent of income.

B. Bounding Consumer Surplus

When the above conditions hold, v_b/v_y is the quality slope of consumer surplus, and it is then possible to compare the surplus and variation measures induced by a change in quality. To establish the comparison, we use the definitions, first of the compensating variation of an increase in b:

$$CV(\Delta b) = m(p,b^0,u) - m(p,b^1,u)$$

$$= \int_{b^0}^{b^1} -m_b \, db \tag{24}$$

and second of the increase in consumer's surplus from an increase in b, <u>if the Willig condition holds</u>:

$$CS(\Delta b) = \int_{b^0}^{b^1} v_b/v_y \; db. \tag{25}$$

By (18) we know that if the Willig condition holds the quality slope of CV ($-m_b$) and the quality slope of CS (v_b/v_y) take the same value when evaluated at b^0, p, and y. So the compensating variation and consumer surplus of a quality change differ depending on how these terms change as we move away from b^0. That is, we are now interested in the second derivative of CV and CS with respect to quality or the quality slopes of v_b/v_y and $-m_b$. To determine these slopes, totally differentiate (18) with respect to quality, giving

$$(26) \qquad -m_{bb} - m_{bv}v_b = \frac{\partial(v_b/v_y)}{\partial b},$$

where $-m_{bb}$ reflects how the quality slope of CV changes as we move away from b^0 and $\partial(v_b/v_y)/\partial b$ reflects how the quality slope of CS changes as we move away. The second term on the left of (26), analogously to the second term in (16), determines the relationship between the compensating variation and ordinary surplus. Hanemann (1980) shows that the sign of m_{bv} is negative if the good is normal and positive if the good is inferior.[5] The term $-m_{bv}v_b$ is positive for normal goods, since $m_{bv} < 0$ and $v_b > 0$. The quality slope of consumer surplus is larger than the quality slope of compensating variation so that the integral over b of v_b/v_y must be larger than the integral over b of $-m_b$. That is

$$(27) \qquad \int_{b^0}^{b^1} (v_b/v_y)\,db > \int_{b^0}^{b^1} -m_b\,db.$$

This lengthy exposition has developed a single point. If x is a normal good and the Willig condition holds, then the compensating variation from an increase in quality is overstated by the consumer surplus measure. Analogous results exist for equivalent variation. Thus ordinary surplus is bounded by CV and EV when the following conditions hold:

a) quality is weakly complementary to some x_i
b) x_i is nonessential
c) v_b/v_{p_i} is independent of income (y).

This result is shown in Figure 1, which illustrates the two schedules for a positive income effect. (In the graph m is shown to be convex in b as proved by Mäler, p. 115.) The slope of $-m_b$ is $-m_{bb}$ and is negative since m is convex in b. The slope of v_b/v_y is $-m_{bb} - m_{bu}v_b$, greater than the slope of

$-m_b$, i.e. less steep, by the positive amount of $-m_{bu}v_b$. When the Willig condition holds, the Marshallian measure for a change in b from b^0 to b^1 overestimates the compensating variation by the shaded area in Figure 1 for positive income effects.

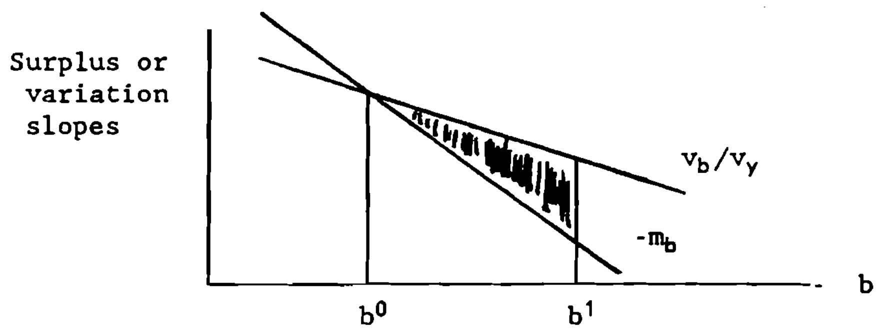

Figure 1

C. Some Intuition about the Relationship between the Compensated and Ordinary Measures

The bounding of consumer surplus by CV and EV is of consequence in the price change case largely because of its connection in the literature with the error in approximation. Of importance are the bounds which can be derived for CV and EV from consumer surplus measures, not the mere ordering of these measures.

In the quality change case it is far more difficult to establish the ordering, but the ordering itself is of less consequence. Despite our habit of making analogies between the welfare theory of price and quality changes, the parallels are not straightforward. As we shall argue in this section, the Willig condition for ordering welfare measures does not ensure that CS will be a good approximation for CV and EV. Conversely, CS may be close or even equal to CV even when the Willig condition is not met.

To establish the correct intuition about quality change results, let us start by exposing the error in a commonly made argument. The argument goes like this. Measuring the value of changes in quality involves simply the calculation of the difference in the value of access under two different quality circumstances. Since the value of access is computed via a price change, and since surplus measures of price changes are often close approximations to variation measures, then the difference between variation and surplus measures for quality changes must be small. Freeman, for example, takes this approach in supporting the use of Marshallian demands for calculating the benefits of environmental improvements (p. 72). This argument is wrong, however, because it neglects differences in shifts of Marshallian and Hicksian demand curves. The Hicksian and the Marshallian demand curves evaluated at the new quality do not cross at the current price.

However, we can exploit our intuition about price changes to some extent. Define $E(\Delta b)$ as the error that results from using Marshallian demands (equation 13) rather than Hicksian demands (equation 6). Assume that weak complementarity holds, so that the change in the area under the Hicksian demand curves equals the complete welfare measure (equation 5). The error can be written as

$$(28) \qquad E(\Delta b) = \int_{p^0}^{\infty} [x^y(p,b^1,y)-x^y(p,b^0,y)]dp - \int_{p^0}^{\infty} [x^u(p,b^1,u)-x^u(p,b^0,u)]dp$$

where the first integral equals the consumer surplus measure, and the second integral equals the correct measure. Rearranging terms gives

$$(29) \qquad E(\Delta b) = \int_{p^0}^{\infty} [x^y(p,b^1,y)-x^u(p,b^1,u)]dp - \int_{p^0}^{\infty} [x^y(p,b^0,y)-x^u(p,b^0,u)]dp.$$

Each integral in the above expression appears to evaluate the difference between the compensating variation and the consumer surplus of a price change, but here the analogy breaks down. This interpretation is correct only for the second integral. Only in this case are we starting at a point where compensated and ordinary demands are equal. At b^0, it is true that $x^y(p^0,b^0,y) = x^u(p^0,b^0,u)$. However, at the new quality level and the existing price, compensated and ordinary demands are not equal, $x^y(p^0,b^1,y) \neq x^u(p^0,b^1,u)$.

To see this, begin at the initial point of correspondence: $x^y(p^0,b^0,m(p,b,u)) = x^u(p^0,b^0,u)$, and consider a change in b:

$$(30) \qquad \partial x^y/\partial b + \partial x^y/\partial y \; m_b = \partial x^u/\partial b$$

which implies, for normal goods, that $\partial x^y/\partial b > \partial x^u/\partial b$. Consequently the first term in expression (29) does not capture the usual difference between the compensating variation and consumer surplus of a price change. We can show an example of the error $E(\Delta b)$ graphically in Figure 2.

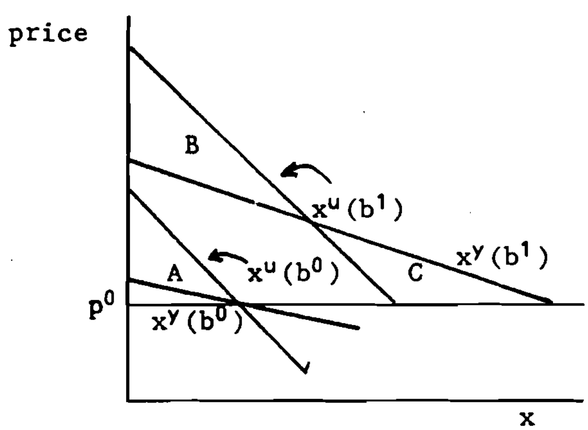

Figure 2.

The error $E(\Delta b)$ equals area A+C-B.

The two new demand functions ($x^y(b^1)$ and $x^u(b^1)$) can cross at p^0 only if either $\partial x^y/\partial y = 0$ (zero income effect) or $m_b = 0$ (a quality change does not matter). In the case of zero income effects, compensated and ordinary demands coincide so that $x^u(b^0)$ and $x^y(b^0)$ are identical and $x^u(b^1)$ and $x^y(b^1)$ are identical. When quality has no effect, $x^u(b^1)$ and $x^u(b^0)$ coincide as do $x^y(b^1)$ and $x^y(b^0)$. In both cases the compensating variation of a quality change equals the equivalent variation and the consumer surplus of the change. In the latter case this is true because all are zero.

While we cannot ascertain this by inspection of Figure 2, the Willig condition ensures that the error will be positive, i.e. the consumer surplus measure will overstate the compensating variation measure for quality increases (from equation 27). However, in the general case there seems no way to determine the sign of the error. It could be positive, negative, or zero depending on the relative sizes of areas A, B, and C. Correspondingly, consumer surplus will be larger, smaller, or equal to compensating variation. For both the welfare theorist and practitioner, the implications are surprising. The ordering of the CV, CS, and EV measures are not tied to the closeness of the approximation. On the one hand, the Willig effect may hold in a situation where there are substantial errors. As an example, consider the demand function

$$x^y(p,b,y) = \exp(a_0 + a_1 p + a_2 y + a_3 b)$$

which exhibits weak complementarity and nonessentiality and meets the Willig condition since income is multiplicatively separable. Yet, considerable differences between $CV(\Delta b)$ and $CS(\Delta b)$ can arise with large values for the coefficient on income.[6]

Just as the presence of the Willig condition is no guarantee that the

Marshallian measure is a good one, its absence does not imply that the Marshallian measure is a poor approximation. Examination of Figure 2 suggests that there can be some non-zero value for $m_b\ \partial x^y/\partial b$ such that compensating variation will equal consumer surplus. For a given non-zero value of this term, the new demand functions may cross at a price which causes area B to just offset areas A+C. Note, however, that equivalent variation will still be different from compensating variation and consumer surplus. This is in direct contrast with the price effect case, where compensating variation equals consumer surplus if and only if the income effect is zero, and in this case they both must equal equivalent variation.

Irrespective of the Willig condition, small income effects will be linked with small errors. From equation (30), smaller income effects make the intersection of $g(p,b',u)$ and $h(p,b',y)$ closer to the current price p^0. Once this is established, we have the standard result that surplus will be a good approximation of CV and EV when income effects are small, thus diminishing the error expressed in (28).

Implications for Behavior and Estimation

Weak complementarity and nonessentiality are characteristics of preferences which imply certain types of behavior. We can use this information on expected behavior to help understand, specify, and estimate recreational demand models.

Nonessentiality is the simplest of the restrictions. The assumption of nonessentiality is reasonable. There are few examples of essential goods, fewer still if one allows for quality differentiation. Hence asserting that a good is nonessential is not likely to be objectionable. Nonessentiality may seem an appropriate but innocuous assumption. Yet it has implications both for the theoretical characterization of the individual's decision problem and for its empirical estimation. It is not enough simply to choose a functional form which has a choke price. Once we correctly acknowledge the nonessentiality of some recreational activity, for example, we must allow for demands for this activity to equal zero. That is, the characterization of the individual's utility maximization process must allow for corner solutions. As long as interior solutions do not always prevail, the functions of interest are not continuous throughout, and classical optimization no longer provides an easy means of characterizing decisions. If decisions are not always restricted to the interior set, then expenditure functions, indirect utility functions, and demand functions are only piecewise continuous. They are continuous only over certain ranges of prices and income which cause the same set of goods to be consumed at non-zero levels.

These features of the theory have empirical implications. Assumptions inherent in conventional regression analysis are violated when dependent variables (decisions) are not restricted to interior solutions. If limit values (e.g. zeroes) actually characterize a subset of these decisions, then econometric estimation is complicated. Including zero observations forces researchers to turn to limited dependent variable estimation techniques. Omitting these observations causes sample selection biases, but also prevents the researcher from learning anything about the participation decision. Understanding and modelling the participation decision is as critical as modelling demand in obtaining welfare measures of quality changes empirically.

We can make the empirical implications of nonessentiality more concrete when we consider it jointly with weak complementarity. Recall that weak complementarity can be characterized in three ways:

i) $$\left.\frac{\partial u(x,b)}{\partial b}\right|_{x_i=0} = 0 \qquad \text{for all } x_j, \quad j\neq i$$

ii) $\lim_{p_i \to \infty} v_b(p,b,y) = 0$ for all y, p_j, $j \neq i$

iii) $\lim_{p_i \to \infty} m_b(p,b,u)$ for all u, p_j, $j \neq i$

Weak complementarity can be confusing. It appears to suggest that when a person does not consume x_i, b does not matter to him, and no change in b can cause him to change his behavior. In fact, a discrete improvement in b can cause an individual to choose a positive value of the good when maximizing utility in the new context, where previously he chose zero. It is in the nature of preferences for nonessential goods that the expenditure function m(p,b,u) and the indirect utility function v(p,b,y) are piecewise continuous, composed of continuous functions which apply at different ranges of p,b space.

With nonessentiality and weak complementarity, we have elements of a theory of participation. That is, finite changes in the price or quality not in the current interior solution can change the set of goods in the interior solution. The choke price is the key to the participation decision. The effect of a quality change on the choke price and hence on the participation decision can be determined by differentiating the indirect utility function. An individual with preferences such that b is weakly complementary to x_i will have a Marshallian choke price, $\tilde{p}_i$, which depends on quality (as well as other exogenous variables): $\tilde{p}_i = \tilde{p}_i(b)$. When this person faces a choke price $\tilde{p}_i$, the indirect utility function will have the property that

$$dv(\tilde{p}_i(b),\bar{p},b,y)/db = v_{p_i} \frac{\partial \tilde{p}_i}{\partial b} + v_b = 0.$$

Dividing by v_y gives

$$\frac{v_{p_i}}{v_y} \frac{\partial \tilde{p}_i}{\partial b} + \frac{v_b}{v_y} = 0 \tag{31}$$

The first term, v_{p_i}/v_y, is zero for $p_i \geq \tilde{p}_i$ because

$$v_{p_i}/v_y = -x_i^y(p_i) = 0.$$

The second term, v_b/v_y, equals zero for $p_i > \tilde{p}_i$ by the definition of weak complementarity.

Nothing about the equality in (31) requires that $\partial\tilde{p}_i/\partial b = 0$. For someone not consuming x_i, changes in b influence the choke price. And this is the key to participation. Increases in b increase the choke price, making participation more likely. Changes which are large enough to move $\tilde{p}_i$ above current price will induce the individual to enter the market. Decreases in b have the opposite effect. Nonessentiality and weak complementarity imply that choice variables which are part of a restricted interior solution will not be influenced by marginal changes in exogenous variables relevant to choice variables excluded from the interior solution. But <u>all</u> exogenous variables determine <u>which</u> choice variables are interior.

The Willig condition (equation 24) is more troublesome and less useful than the other restrictions. The presence of this condition implies that the surplus measure is bounded by the variational measures. In the price change case, bounding of consumer surplus by variational measures is important, because it is coupled with the result that the error between surplus and variational measures is likely to be small. But the Willig condition tells us nothing about the size of the error in the quality change case. Additionally, even in the absence of the Willig condition, the difference between CS(Δb) and CV(Δb) may be small or zero, although both will be quite different from EV(Δb).

By itself, the Willig condition provides little help, either empirically or conceptually. The income effect is a more useful indicator. It is true that consumer surplus may be a good approximation to the more appropriate variational measure even when income effects are large, but small income effects will ensure small errors.

Even when one is convinced that the above conditions characterize preferences, it is difficult to devise a functional form which is easy to estimate, meets all of the above requirements, and fits the data well. One alternative is to estimate a flexible functional form, placing particular weight on the criterion that the function fit the data. Working entirely with observable behavior, a good fitting demand function, even if it does not integrate back to an indirect utility function which meets Willig's condition, may generate consumer surpluses which are close approximations to the true surpluses. If this route is followed, however, one should not attempt to extract the more precise Hicksian measure of variation from such a model.

There is some evidence that this approach is a reasonable one. Kling, working in a simulation framework where her preferences were known, shows that Marshallian measures from different demand functions are fairly robust approximations of the true variational measures. In empirical settings, where true preferences are not known, changes in areas under different Marshallian demand functions typically give similar measures of consumer surplus. After all, observations on behavior under different settings allow us to approximate the change in the value of access, and this is the essence of valuing changes in the quality characteristics of goods. The validity of this approach still requires that nonessentiality and weak complementarity are apt characterizations of preferences. If they are not, there is no guarantee that information about the welfare effects of quality changes can be deduced at all from observations on behavior.

Conclusion

The model of quality-differentiated goods provides a reasonable basis for measuring the welfare effects of exogenous changes in quality. While the theory that serves as a basis for welfare measurement of quality changes is not as complete as that for price changes, it nevertheless establishes a plausible set of relations between welfare measurement and behavior. Welfare measurement in the quality-differentiated goods model rests on two aspects of preferences: weak complementarity and nonessentiality. Weak complementarity is the key concept. It describes the technical conditions connecting behavior with the theoretically correct welfare measure, and it provides an intuitive explanation of the welfare measures.

How do we know whether weak complementarity holds? Given the key role of this restriction, this question becomes the central question in welfare measurement of quality changes. There are two approaches to establishing weak complementarity, one by a scheme of hypothesis testing, the other by assumption. Hypothesis testing is possible because weak complementarity has a number of behavioral implications which can be couched in the form of whether parameters on behavioral models are zero. For example, weak complementarity implies that in a two-good system, a consumer of good one but not good two will not respond to marginal changes in the quality of good two. In the right model, this assumption is testable. A series of such tests could tell us whether behavior is consistent with weak complementarity.[7]

We believe that it is appropriate to assume weak complementarity, depending on the setting. Treating weak complementarity as an assumption makes welfare measurement vulnerable to the failure of the assumption. What are the implications of measuring areas under demand curves when it fails? Intuitively, weak complementarity can fail for two reasons. First, preferences which include non-use value, such as existence value, violate weak complementarity. Second, weak complementarity to one good does not hold when the resource serves as the characteristic of several goods.

In the first case, intrinsic value or existence value is missed. While this missing value is typically taken to be positive implying that use value is a lower bound to total value, it need not always be so. While some individuals may have altruistic and other socially motivated interests in the quality of a good, others might prefer that if they are priced out of the market for a good, no one else enjoy it. However, suspicions of small non-use values or prior expectations on their signs may make areas behind demand functions still useful even in the absence of weak complementarity. In the second case, when weak complementarity fails because other goods are related to quality, the area under one demand curve may under- or overestimate the true value of the welfare change depending on the substitutability between the related goods.

When we adopt weak complementarity by assumption, we resign our methods to dealing only with Marshallian demand functions and their implications. Attempting to calculate variational welfare measures by integrating back to cost functions in the absence of weak complementarity can result in enormous errors. Further, the Willig condition, while of limited use with weakly complementary preferences, provides no help without such preferences.

Footnotes

1 These bounds are likely to be small with small income effects. Additionally, the compensated curve can, under some circumstances, be recovered from the ordinary demand function by integrating back to the expenditure function, even when income effects exist. This is practically feasible only in the two-good case, and even then raises questions. A demand function with relatively few parameters may capture behavior well, but when integrated back may give quite implausible preference functions. It is reasonable to stick with good measures of behavior.

2 Throughout we adopt the convention of defining variation measures so that they have the same sign as the utility change. Thus if $b^1 > b^0$, the CV(Δb) in (5) will be positive.

3 However, it is not necessarily true that a finite consumer surplus implies nonessentiality. Denoting x^y as the Marshallian demand, it is possible for the limit of x^y to equal 0 as $p \to \infty$ even when the limit of x^u does not equal 0 as $p \to \infty$. Given prices and income, the individual may maximize utility at x^y = 0 even if x is essential, but there will be no prices of other goods low enough nor income high enough to compensate for his being forced out of the market for x.

4 This is true because

$$\int_{p^0}^{\bar{p}} \frac{\partial x^y}{\partial b}\, dp = \frac{\partial}{\partial b} \int_{p^0}^{\bar{p}} x^y(\cdot)\, dp,$$

where the reversal of integration and differentiation is possible because $x^y(\bar{p})$ equals 0 and p^0 is a constant.

[5] Summarizing this proof, the good is normal or inferior as $\partial x/\partial y$ is positive or negative. The income effect can be written

$$\frac{\partial x}{\partial y} = \frac{\partial(-v_p/v_y)}{\partial y} = \frac{-v_y v_{py} + v_p v_{yy}}{v_y^2} = \frac{v_p}{v_y} \; \frac{(v_{yy} - \frac{v_y}{v_p} v_{py})}{v_y} .$$

But if v_p/v_b is independent of income as is required by Willig's conditions for (26) to hold, then

$$v_{py} = \frac{v_{by} v_p}{v_b}$$

so that

$$\frac{\partial x}{\partial y} = \frac{v_p}{v_y} \; \frac{\left\{v_{yy} - v_{by} \frac{v_y}{v_b}\right\}}{v_y} .$$

Since $v_y > 0$ and $v_p/v_y = -x < 0$, the term $(v_{yy} - v_{by} \; v_y v_b)$ will take on the opposite sign from $\partial x/\partial y$. Now, by differentiating the following

$$m_b(p,b,v) = - \frac{v_b(p,b,m(p,b,u))}{v_y(p,b,m(p,b,u))}$$

with respect to u we get

$$m_{bv} = \frac{v_{by} m_v v_y - v_b v_{yy} m_v}{-v_y^2}$$

$$= \frac{v_{by} - v_{yy} \frac{v_b}{v_y}}{-v_y^2}$$

$$m_{bv} = \frac{v_b}{v_y} \left[\frac{v_{yy} - v_{by} \; v_y/v_b}{v_y^2}\right] .$$

Since v_b, v_y and $v_y{}^2$ are all positive, m_{bv} will take on the sign of $(v_{yy}-v_{by}v_y/v_b)$ which, from above, is - sign $(\partial x/\partial y)$.

[6] For example, for the case $x = \exp(-2 + b - p + 2y)$ when $p = 1$, $y = 1$, the CS for moving b from 0 to .5 overstates the CV by more than 20 percent.

[7] For example, in the Smith-Desvousges work, when the demand function is $x = \exp(a_0(b) + a_1(b)p + a_2(b)y)$ where $a_i(b)$ represent linear functions of b. Weak complementarity holds if $a_2(b) = 0$. This is a testable hypothesis in any framework which estimates the parameters a_i.

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ESTIMATION EFFICIENCY AND PRECISION OF BENEFIT ESTIMATES FROM USE OF DOUBLE BOUNDED DICHOTOMOUS CHOICE CONTINGENT VALUATION

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Michael Hanemann, John Loomis, and Barbara Kanninen

Abstract

While there are many advantages to standard dichotomous choice contingent valuation questions, one troublesome feature is that only a minimal amount of information about respondent's willingness to pay is obtained. At the other end of the spectrum is iterative bidding, whereby a series of dichotomous choice questions are asked, but only information on the final value is recorded. While this obtains more information from the respondent it is not without cost to the respondent and interviewer. This paper shows that the statistical efficiency and hence precision of willingness to pay estimates can be markedly improved by asking each respondent just two linked dichotomous choice questions. The pattern of these questions is similar to a iterative bidding sequence, but stops at the second round. Rather than recording the point estimate, the answers to the yes/no questions are recorded and used to estimate a double bounded logit equation. Results from a survey of California residents regarding their willingness to pay to protect wildlife resources in the San Joaquin Valley shows that the confidence interval on the benefit estimates can be substantially tightened using the double bounded logit approach. In addition the gain in statistical precision with the double bounded logit equation would allow reduction in the large sample size requirements associated with standard single bound dichotomous choice surveys.

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INTRODUCTION

The Contingent Valuation Method has become one of the standard approaches for valuing non marketed resources such as recreation, wildlife and environmental quality. All applications of CVM involve three central features: (1) description of the resource to be valued; (2) means by which the respondent will pay, sometimes referred to as the payment vehicle; (3) the value elicitation procedure. It is the value elicitation process that is of interest to us in this paper.

Initially, a bidding format was used as the value elicitation process, whereby the interviewer would provide some starting dollar amount and ask the respondent if they would pay this amount or not. If the respondent indicated they would pay that amount, the amount was raised. The process was repeated until the respondent was "bid" up to their maximum willingness to pay. If the respondent indicated they would not pay the initial amount, the amount was lowered until the first yes, would pay was recorded.

An alternative elicitation approach was developed by Bishop and Heberlien (1979). Rather than require the respondent to answer a series of yes/no questions to higher and higher dollar amounts, they simply asked each respondent about a single dollar amount. This dollar amount is treated as a threshold. If a person values the good more highly than the threshold dollar amount, they will answer yes they would pay. If they value the good less than the threshold dollar amount they would state no. By asking a large sample of people a large range of dollar amounts, a logit or probit equation can be estimated that relates probability of a yes response to the dollar amount a person was asked to pay. From the estimated logit/probit equation, willingness to pay can be inferred. (See Hanemann, 1984 for details).

In some sense the traditional bidding method and single bound dichotomous choice question represent bipolar ends of a continuum. At the bidding end, the respondent is asked a series of dichotomous choice questions until some point estimate is reached. The interviewer typically records only the final point estimate. While that point estimate contains a great deal of information, it is quite costly in terms of interview time and mental effort on the respondent. This limits the number of WTP questions which can be asked and hence the usefulness of CVM for addressing alternative policies affecting environmental quality. At the other end of the spectrum is single bound dichotomous choice CVM. Here only one dichotomous choice question is asked. While it is easy on the respondent it yields very little information per respondent. Hence the single bound dichotomous choice question is statistically inefficient and requires a much larger sample to attain a given level of precision.

This paper demonstrates that the statistically efficiency of dichotomous choice CVM and the precision of WTP estimates can be improved by asking the respondent to engage in two linked rounds of bidding: answer yes (no) to the first dollar amount and then, depending on that first response, to answer an additional question to a higher (lower) dollar amount. The responses to both rounds of questions are recorded and utilized in the estimation, the details of which are discussed in the next section.

THEORY

To begin with, the basic structure of the dichotomous choice CVM method will be presented for the single bound approach. Then this approach will be extended to the double bound. Using this framework the differences in the variance-covariance matrix of standard single and double bound are derived.

Differences in the variance-covariance matrix translate into different levels of precision in the benefit estimates.

The general structure of a discrete choice CVM survey involves asking an individual if he or she would pay \$B to secure a given improvement in environmental quality. The probability of obtaining a "No" or a "Yes" response can be represented, respectively by the statistical models:

(1) $\pi_n \ (B) = G(B;\theta)$

(2) $\pi_y \ (B) = 1-G(B;\theta)$

where $G(\cdot;\theta)$ is some statistical distribution function with parameter vector θ. As pointed out in Hanemann (1984), this statistical model can be interpreted as a utility maximization response within a random utility context where $G(\cdot;\theta)$ is the cdf of the individual's true maximum willingness to pay. Since utility maximization implies:

Pr{ No to \$B} <==> Pr{ \$B > maximum WTP}

Pr{ Yes to \$B} <==> Pr{ \$B ≤ maximum WTP}

In Bishop and Heberlein's (1979) pioneering study, $G(\cdot;\theta)$ is the log-logistic cdf:

(3) $G(B) = [\ 1 + e^{a+b(\ln \$B)}]^{-1}$

where $\theta \equiv (a,b)$. Another alternative is the logistic cdf:

(4) $G(B) = [\ 1 + e^{a+b(\$B)}]^{-1}$.

In both cases, (1) and (2) correspond to a form of the logit model. Similarly, if one were to substitute the lognormal or normal cdf's for (3) and (4), (1) and (2) would correspond to a probit model. Other distribution functions could readily be employed, although logit and probit models are by far the most common to date.

While there are other estimation techniques with equivalent asymptotic properties, it is convenient to focus on the maximum likelihood approach. In general, the participants in a CVM survey will be offered different bids. Suppose there are N participants, and let Bi be the bid offered to the ith individual. Then, the log-likelihood function for this set of responses is:

$$(5)\ \ln L(\theta) = \sum_{i=1}^{N} \ln Li(\theta)$$

$$= \sum_{i=1}^{N} I(Bi) \ln \ (Bi) + (1-I(Bi) \ln \ \ (Bi)$$

$$= \sum_{i=1}^{N} I(Bi) \ln [1-G(Bi;\theta)] + [1-I(Bi)] \ln G(Bi;\theta)$$

where the Indicator function (I(Bi)) = 1 if the ith response is 'yes' and zero otherwise.

Here Li(θ) is the ith individual's contribution to the likelihood function, which is given by π_y for those who responded "Yes" and π_n for those who responded "No". For logit and probit models, McFadden (1974) and Haberman (1974) established the global concavity of the log-likelihood function; thus in these cases the matrices

$$\frac{\partial^2 \ln \ Li}{\partial\theta \quad \partial\theta'}$$

are negative definite for all i. The maximum likelihood estimator, denoted $\hat{\theta}$ is the solution to the equation

$$(6) \qquad \frac{\partial \ln L(\hat{\theta})}{\partial\theta} = 0.$$

As proved, for example, in Amemiya (1985), this estimator is consistent (though it may be biased in small samples) and asymptotically efficient. Thus the asymptotic variance-covariance matrix of θ is given by the Cramer-Rao lower bound

(7) $$V(\theta) = \left[-E \frac{\partial^2 \ln L}{\partial\theta\, \partial\theta'} \right]^{-1}$$

Double Bounded Logit

So far we have been describing a conventional dichotomous choice CVM survey in which the participants are each presented with a single bid. Now consider an alternative format in which each participant is presented with two bids. The level of the second bid is contingent upon the response to the first bid. If the individual responds "Yes" to the first bid, the second bid (to be denoted $B^u i$) is some (random) monetary amount greater than the first bid ($Bi < B^u i$); if the individual responds "No to the first bid, the second bid ($B^d i$) is some amount smaller than the first bid ($B^d i < Bi$). Thus the overall survey has four possible outcomes: (a) both answers being "Yes"; (b) both answers being "No"; (c) a "Yes" followed by a "No" and (d) a "No" followed by a "Yes". The likelihood of these outcomes will be denoted respectively by π_{yy}, π_{nn}, π_{yn} and π_{ny}. Under the assumption of a utility maximizing respondent, the formulas for these likelihoods are as follows. In the first case, we have

$B^u i > Bi$ and

(8) $$\begin{aligned} \pi_{yy}(B^u i, Bi) &= \Pr\{Bi \le \max WTP \text{ and } B^u i \le \max WTP\} \\ &= \Pr\{Bi \le \max WTP \mid B^u i \le \max WTP\} \Pr\{B^u i \le \max WTP\} \\ &= \Pr\{B^u i \le \max WTP\} \\ &= 1 - G(B^u i;\theta) \end{aligned}$$

since with $B^u i > Bi$, $\Pr\{Bi \le \max WTP \mid B^u i \le \max WTP\} \equiv 1$.

Similarly, with $B^d i < Bi$, $Pr\{B^d i \leq \max WTP \mid Bi \leq \max WTP\} \equiv 1$.

Hence,

(9) $\pi_{nn}(Bi, B^d i) = Pr\{Bi > \max WTP \text{ and } B^d i > \max WTP\} = G(B^d i, \theta)$.

When a "Yes" is followed by a "No", we have $B^u i > Bi$ and

(10) $\pi_{yn}(Bi, B^u i) = Pr\{Bi \leq \max WTP \leq B^u i\}$

$= G(B^u i; \theta) - G(Bi; \theta)$

and when a "No" is followed by a "Yes" we have $B^d i < Bi$ and

(11) $\pi_{ny}(Bi, B^d i) = Pr\{Bi \geq \max WTP \geq B^d i\} = G(Bi; \theta) - (B^d i; \theta)$.

As Equations 10 and 11 demonstrate, in two of the four cases the second bid allows the researcher to bound the respondents' unobserved WTP. In equations 8 and 9, the second bid raises and lowers, respectively, the threshold on WTP.

The log-likelihood function for the double bounded approach takes the form:

$$\begin{aligned}(12)\ \ln L^D(\theta) = \sum_{i=1}^{N} \{&I(Bi)\, I(B^u i) \ln \pi_{yy}(Bi, B^u i) + \\ &(1-I(Bi))(1-I(B^d i)) \ln \pi_{nn}(Bi, B^d i) + \\ &I(Bi)(1-I(B^u i)) \ln \pi_{yn}(Bi, B^u i) + \\ &(1-I(Bi))(I(B^d i)) \ln \pi_{ny}(Bi, B^d i)\}\end{aligned}$$

Where $I(\cdot)$ is the indicator function defined as before.

The maximum likelihood estimator for the double bounded approach, $\hat{\theta}^D$, is obtained by solving an equation analogus to (6) but for equation (12). The asymptotic variance covariance of θ^D is given by the analog of (7):

$$(13)\ V(\theta^D) = \left[- E \frac{\partial^2 \ln L^D}{\partial\theta \quad \partial\theta'} \right]^{-1}$$

With regard to the comparison between the estimators $\hat{\theta}$ and $\hat{\theta}^D$, the following result is established in the appendix:

THEOREM: If the likelihood function (5) is globally concave in θ, it follows that $V(\theta) \geq V(\theta^D)$.

The implication is that the estimator $\hat{\theta}^D$ is asymptotically more efficient than the estimator $\hat{\theta}$. The reduction in variance can be translated into tighter confidence intervals for the WTP estimates by adapting an approach first suggested by Krinsky and Robb (1986) for elasticities. The degree of gain in efficiency is, of course, an empirical issue that will vary from sample to sample. The following example is provided to demonstrate the application of the double bounded method and illustrate how large this reduction in variance can be for at least one data set.

METHODS

To illustrate the comparison between single and double bounded logit, only a simple specification with an intercept and a slope coefficient on bid will be estimated. The approach can be applied with multiple independent variables but for comparative evaluation of the two approaches it is not necessary here. We also adopt a linear in bid logit specification, although the approach works equally well for the log of bid logit specification.[1]

Since the single bound case reflects the standard log-likelihood function, the Shazam package was used to estimate the logit equations presented below in Table 1. To implement the double bounded approach which involved four log-likelihood functions, GQOPT was used. The four log-likelihood functions implicit in equation 12 were programmed into a Fortran subroutine. The subroutine reads each individual's responses, determines which log-likelihood function to apply, then calculates the individual log-likelihood function. Finally, the sum of all of the individual log-likelihood functions is computed. It is this resulting log-likelihood function that is maximized by GQOPT. This log-likelihood function was maximized by using a simplex algorithm to find starting values and then applying a Davidson-Fletcher-Powell (DFP) method to find the maximum.

RESEARCH DESIGN

To allow testing of the statistical efficiency of double versus single bounded dichotomous choice questions, a set of survey questions were developed. Each person was first asked a single dichotomous choice question about maintaining the current amount of wetlands and waterbirds in the San Joaquin Valley. Consistent with the voter referendum format chosen, the payment vehicle was additional taxes. If they answered yes to the first dollar amount (Bi), they were asked if they would vote in favor of the program if it cost a specified higher level of taxes (that was approximately double the original amount). If they answered no to the first dollar amount they were asked if they would vote in favor of the program if it had a specified smaller increase in additional taxes (that was about half as much as the original amount).

The exact wording of the question sequence for Wetland Maintenance is: "If the Maintenance program were the only program you had an opportunity to vote on, and it cost every household in California $Bi dollars each year in additional taxes would you vote for it?"

The follow up question was: "What if the cost were $\$B^{d}i$" if said no to $Bi (where $\$B^{d}i < \$Bi$) or "What if the cost were $\$B^{u}i$" if said yes to $Bi (where $\$B^{u}i > \$Bi$). The range of the dollar bid amounts in the initial question (the Bi's) were $30 to 130 for the Maintenance questions and $45 to $225 for the Improvement questions.

This format of question was asked for a Wetlands Improvement program, Wildlife Contamination Control Maintenance and Improvement programs, and a San Joaquin River and Salmon Improvement Program. There are five WTP questions that were asked with this format. The resulting benefit estimates reflect annual household total WTP including recreation use, option and existence values (Randall and Stoll, 1983, Loomis, et al, 1984).

To compare the single and double bounded approach, the follow up bid and response to it are ignored in estimating the traditional single bound logit equation but included in the double bound estimation.

The double and single bounded approach will be compared to each other with respect to the precision of the estimated coefficients, goodness of fit measures, and confidence intervals for the benefit estimates. The confidence intervals for the benefit estimates are derived using an adaptation by Park, et al., of an approach suggested by Krinsky and Robb (1986) for elasticities that is explained in greater detail below.

DATA COLLECTION AND DATA SOURCES

The data collection procedure used in this study involved a combination of mailing a survey booklet to the respondent and then conducting the interview over the phone. Specifically, the actual interview and data collection from the respondent took place over the telephone. However, the respondent did have a survey booklet in front of them at the time of the interview.

Initial phone calls were made to random samples of households in the San Joaquin Valley and rest of California to solicit their participation in the study. A total 1573 households were contacted and 991 households were scheduled for interviews, for a participation rate of 63%. Of these 991 households, 803 (227 in the San Joaquin Valley and 576 in the rest of

California) completed the interview when called back after receiving the survey booklet. This represents an overall completion rate of 51% for both steps. As is normal for all CVM studies, the completed questionnaires were screened for protest responses to the willingness to pay question. Protests reflected about 3-5% of the San Joaquin Valley and rest of California residents samples. This low protest rate indicates that nearly all respondents found the voter referendum format and the payment vehicle credible and acceptable.

Since one of the key elements in the double bounded approach is the ability to bracket a respondent's WTP between Bi and either B^ui or B^di it is worth noting what percentage of respondents fell into these cases. Over the five questions asked to San Joaquin Valley residents between 33% and 44% of the responsent's WTP were bounded. For California residents outside the San Joaquin Valley, between 33% and 49% of the respondent's WTP were bounded.

ESTIMATION RESULTS

Table 1 presents the logit equations estimated using the double and single bound approach for both residents of the San Joaquin Valley and rest of California.

INTERPRETATION

As Table 1 illustrates, the single bounded logit equations have much lower t statistics, implying much larger standard errors on the bid coefficients than the double bounded logit estimates. In fact half of the single bounded estimates of the slope coefficient are not statistically different from zero at the 10% level. Relatively speaking, the standard errors on the single bounded logit are nearly five to ten times larger than on the double bounded bid coefficient. This has important implications for the precision of the benefit estimates derived from the equations. Specifically,

TABLE 1
COMPARISON OF ESTIMATED SINGLE AND DOUBLE BOUND LOGIT EQUATIONS

PROGRAM/LOCATION	METHOD			
	SINGLE BOUND		DOUBLE BOUND	
	INTERCEPT	SLOPE	INTERCEPT	SLOPE
WETLAND MAINTENANCE				
CALIFORNIA	2.68	-0.0107	3.77	-0.0249
(T Statistics)	(6.51)	(-1.91)	(16.74)	(-13.94)
(CHI-SQ - PSUEDO R SQ)	3.56	0.01	161.48	0.16
SAN JOAQUIN VALLEY	2.37	-0.0108	3.80	-0.022
	(3.96)	(-1.36)	(9.88)	(-7.52)
	1.04	0.01	44	0.24
WETLAND IMPROVEMENT				
CALIFORNIA	1.94	-0.0077	3.042	-0.0123
	(6.76)	(-3.97)	(17.73)	(-14.75)
	16.10	0.03	281.18	0.23
SAN JOAQUIN VALLEY	1.23	-0.0038	2.80	-0.010
	(2.81)	(-1.30)	(10.08)	(-8.27)
	1.67	0.01	119.02	0.266
CONTAMINATION MAINTENANCE				
CALIFORNIA	3.35	-0.0158	3.61	-0.0194
	(7.62)	(-3.35)	(17.49)	(-14.57)
	11.14	0.03	115.48	0.12
SAN JOAQUIN VALLEY	2.21	-0.005	3.65	-0.0187
	(3.47)	(-.70)	(12.05)	(-9.63)
	0.48	0.01	51.12	0.14
CONTAMINATION IMPROVEMENT				
CALIFORNIA	1.74	-0.00634	2.87	-0.0095
	(6.40)	(-3.96)	(17.74)	(-14.86)
	16.0687	0.03	347.74	0.28
SAN JOAQUIN VALLEY	0.909	-0.00237	2.434	-0.0070
	(2.17)	(-.952)	(9.77)	(-8.14)
	0.91	0.01	140	0.3
SALMON IMPROVEMENT				
CALIFORNIA	2.18	-0.0068	3.450	-0.0192
	(6.10)	(-1.68)	(16.85)	(-14.04)
	2.77	0.01	289.78	0.254
SAN JOAQUIN VALLEY	2.531	-0.0122	3.10	-0.0156
	(4.34)	(-2.02)	(10.16)	(-7.81)
	4.07	0.02	68	0.184

even if the point estimates presented in Table 2 below were similar, the confidence interval around the benefit estimates would be quite a bit more precise for the double bound as compared to the single bound.

In addition both goodness of fit measures (the Chi-square and the psuedo R square) are substantially higher for the double bounded logit equations as compared to the traditional single bounded equations. The pseudo R squared for the single bound range from .01 to .03, whereas for the double bound the psuedo R square ranges from .12 to as high as .3.

COMPARISON OF BENEFIT ESTIMATES

Table 2 presents the benefit estimates (compensating surplus) for the double and single bound approach for both residents of the San Joaquin Valley and rest of California. These benefit estimates reflect the mean willingness to pay associated with the linear logit equation. The mean is computed following Hanemann (1989: 1059) as:

$$WTP = (1/B1) * \ln(1+e^{Bo}) \quad (14)$$

where Bo is the intercept and B1 is the slope coefficient on bid.

Table 2 illustrates the differences in benefit estimates. For this data set, the double bounded logit results in WTP estimates that are 80% as large as the single bounded, although there are exceptions even with this data set. However, this overall trend may be due to the rather limited range of bid amounts asked which results in a more inelastic price response in the single bounded logit equation. The introduction of the additional information about how the respondent answered the subsequent follow up question, provides an upper bound to the threshold value for many respondents.

COMPARISON OF PRECISION OF BENEFIT ESTIMATES

Of particular interest in Table 2 is the comparison of confidence intervals for the single and double bounded logit. The confidence intervals

TABLE 2
COMPARISON OF BENEFIT ESTIMATES FROM SINGLE AND DOUBLE BOUNDED LOGIT

PROGRAM/LOCATION	METHOD			
	SINGLE BOUND		DOUBLE BOUND	
	MEAN	90% C.I.	MEAN	90% C.I.
WETLAND MAINTENANCE				
CALIFORNIA	$257	167-983	$152	123-188
SAN JOAQUIN VALLEY	$228	132-1458	$174	157-196
WETLAND IMPROVEMENT				
CALIFORNIA	$269	231-360	$251	235-268
SAN JOAQUIN VALLEY	$391	74-2241	$286	255-325
CONTAMINATION MAINTENANCE				
CALIFORNIA	$214	171-345	$187	177-199
SAN JOAQUIN VALLEY	$463	167-3698	$197	179-216
CONTAMINATION IMPROVEMENT				
CALIFORNIA	$300	248-431	$308	289-331
SAN JOAQUIN VALLEY	$526	257-4173	$360	317-415
SALMON IMPROVEMENT				
CALIFORNIA	$336	206-1681	$181	171-193
SAN JOAQUIN VALLEY	$214	153-706	$202	180-231

were calculated using Park, et al.'s adaptation of Krinksy and Robb (1986) technique for calculating confidence intervals for elasticities. This approach involves three steps: (1) a multivariate normal distribution for the estimated parameters is constructed having as its mean the parameter estimates, and having its variance developed from the parameter's variance-covariance matrix. (2) a large number of draws (here 4,000) are made from the resulting multivariate normal distribution. At each draw, the resulting parameters are used to calculate WTP; (3) The vector of WTP are ranked and 5%

of the WTP estimates in each tail are dropped to form a 90% confidence interval on WTP.

The confidence intervals presented in Table 2 show a dramatic improvement in precision associated with the double bounded estimating technique. Even if one compares only the cases where both the single and double bound had statistically significant (at the 10% level) slope coefficients, the differences in precision are still quite large. Specifically, if one calculates the percentage each bound is of the mean WTP the following comparison is made: a) the lower limit of the 90% confidence interval is 25% of the single bound mean, but only 10% of the double bound mean, for a two and a half times difference; b)the upper limit of 90% confidence interval is 154% of single bound mean, but 13% of the double bound mean, for a difference by a factor of 12. This substantial increase in precision does not require an increase in the number of individuals surveyed, only that each person be asked a second dichotomous choice question.

CONCLUSION

For this data set it appears that a substantial increase in the precision of the estimated logit coefficients and willingness to pay estimates can be achieved by simply iterating one more time in the traditional dichotomous choice question. The traditional approach resulted in insignificant coefficients on the bid variable in half of the programs. All of the double bounded estimates were statistically significant, all at the 1% level or better. The confidence interval for benefit estimates were two and half to 12 times wider with the single bounded method as compared to the double bounded method. All of this increase in estimation efficiency and precision in benefit estimates was accomplished with the same size sample of individuals. Rather it involved asking a follow-up dichotomous choice question, with the bid amount varying depending on the answer to the first dichotomous choice question. This approach proved quite feasible for five willingness to pay questions in a telephone survey. The approach is feasible for mail surveys as well (Wegge, Hanemann, Strand, 1986). At present, the biggest drawback to widespread implementation of the double bounded approach is the added complexity in the estimation algorithm.

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FOOTNOTES

1. The likelihood function, statistical results and benefit estimates calculated using the log of bid amount in the logit equations yielded empirical results qualitatively identical to what is reported in this paper for the linear logit. Results of the log of bid results are available from the authors.

APPENDIX

<u>Theorem</u>: $V(\theta^D) \leq V(\theta)$

<u>Proof</u>: Since $V(\theta) = \left[-E \dfrac{d^2 \ln L}{d\theta d\theta'}\right]^{-1} = \left[I(\theta)\right]^{-1}$

where $I(\theta)$ is the information matrix,

$V(\theta^D) \leq V(\theta)$ is equivalent to $I(\theta^D) \geq I(\theta)$.

For simplicity, assume $Bi = B \; \forall \; i$ and $Bi^u = B^u$, $Bi^d = B^d \; \forall \; i$.

from (12) we can find:

$$
\begin{aligned}
I(\theta^D) = & \frac{1}{1 - G(B^u)} \left[G_\theta(B^u)\right]\left[G_\theta(B^d)\right]' \\
& + \frac{1}{G(B^d)} \left[G_\theta(B^d)\right]\left[G_\theta(B^d)\right]' \\
& + \frac{1}{G(B^u) - G(B)} \left[G_\theta(B^u) - G_\theta(B)\right]\left[G_\theta(B^u) - G_\theta(B)\right]' \\
& + \frac{1}{G(B) - G(B^d)} \left[G_\theta(B) - G_\theta(B^d)\right]\left[G_\theta(B) - G_\theta(B^d)\right]'
\end{aligned}
$$

and from (5):

$$
\begin{aligned}
I(\theta) = & \frac{1}{1 - G(B)} \left[G_\theta(B)\right]\left[G_\theta(B)\right]' \\
& + \frac{1}{G(B)} \left[G_\theta(B)\right]\left[G_\theta(B)\right]'
\end{aligned}
$$

$I(\theta^D) - I(\theta) =$

$$\frac{1}{(G(B^u) - G(B)(1-G(B)(1 - G(B^u)} \left[G_\theta(B) - G_\theta(B^u) - G_\theta(B)G(B^u) + G_\theta(B^u)G(B)\right] \times$$

$$\left[G_\theta(B) - G_\theta(B^d) - G_\theta(B)G(B^d) + G_\theta(B^d)G(B)\right]'$$

$$+ \frac{1}{G(B^d)\left[G(B) - G(B^d)\right]G(B)} \left[G_\theta(B^d)G(B) - G_\theta(B)G(B^d)\right]\left[G_\theta(B^d)G(B) - G_\theta(B)G(B^u)\right]'$$

Both of these terms are positive semidefinite.

Therefore $I(\theta^D) \geq I(\theta)$ and $V(\theta^D) \leq V(\theta)$.

THE EFFICIENCY OF DISCRETE CHOICE ESTIMATION

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Introduction

Consider the linear regression model:

$$y_i = \alpha + \gamma x_i + \varepsilon_i \ , \qquad (1)$$

where the x's are assumed to be fixed and the disturbance term, ε, is distributed *i.i.d.* with mean zero and a finite variance, σ^2. Suppose that instead of observing y_i one observes only an indicator variable $I[y_i; c_i]$ which takes on the value 1 if $y_i \geq c_i$ and 0 otherwise. This is one of several ways to get a binary data model.[1] However, due to the loss of information that occurs when y_i is replaced by an indicator variable, we expect the maximum likelihood estimator from the binary choice model to be less efficient than the MLE from the uncensored sample. This paper considers alternative maximum likelihood estimators and focuses on two related questions: (1) how efficient is parameter estimation using the indicator variable $I[y_i; c_i]$ relative to using the actual variable y_i and (2) how is that relative efficiency influenced by the choice of c_i.

We consider two situations. In the first, each of the $i = 1, ..., n$ agents in the sample is randomly assigned potentially different threshold levels, while in the second each of the i agents is assigned the same threshold, c. The second situation is essentially a special case of the first where all c_i equal c. The former is common in the biological sciences, where c_i is the dose of a certain treatment that is applied to subject i, but has recently become quite popular in marketing research and among researchers using contingent valuation techniques to value non-marketed goods such as environmental amenities. [2] The second situation is usually found in the social sciences and, in particular, is used extensively in labor economics.[3] We show that in both situations that the choice of the threshold level(s) can have a large influence on the relative efficiency of the estimates of the parameters of interest.

Changing the threshold(s) fundamentally changes the indicator variable, $I[y_i; c_i]$. We are interested in cases where c_i can be chosen and, as a consequence, the particular form of the indi-

[1] The debate over whether an underlying continuous variable lies behind each dichotomous or polychotomous variable began with the exchange between Pearson and Yule in 1900 and has had a long and colorful history.

[2] See for instance Bishop and Heberlein (1979), Hanemann (1984), Cameron and James (1987a,b), and Mitchell and Carson (1989).

[3] See for instance Maddala, 1983.

cator variable is under the researchers' control. We explore experimental designs which minimize the loss in efficiency from having to use a binary discrete choice indicator variable rather than using a sample containing y_i.[4] A clear implication of our work is that economists should not wait and passively accept the survey data from various sources but rather should be involved in the design of the survey from the beginning, paying particular attention to the threshold level(s) used in the survey.

Our work can be seen as an extension, in the direction of discrete choice estimation, of earlier work by econometricians (Conlisk, 1973; Aigner and Morris, 1979) on optimal design for economic experiments with continuous response variables. These results are complementary to earlier work on choice based sampling (Manski and Lerman, 1977; Manski and McFadden, 1981) in that, instead of designing sampling schemes and estimation strategies which exploit the known choice patterns of agents, we are defining the choices of agents through the survey designer or experimenter's choice of c_i. Our work also has interesting implications for the "matching" versus "choice" issue recently raised by prominent cognitive psychologists (Tversky, Slovic, and Kahneman, forthcoming) in terms of the informational content of the two different forms of behavioral response. Throughout our paper, we draw heavily from the biometrics literature (Finney, 1978; Silvey, 1980) on the optimal design of dose-response experiments.

The paper is organized as follows. Section 1 presents two simple examples which illustrate the basic intuition behind the single and multiple threshold cases and introduces some notation. Section 2 introduces covariates. Section 3 introduces a previously established optimality result which shows that typically one and at most two threshold levels are all that are needed to minimize the variance of the estimate of a particular percentile. This section also looks at maximum relative efficiency in the context of alternative distributions. Section 4 looks at the implications of different concepts of optimality on the design chosen and introduces the problem of uncertainty about the true parameter values when determining the set of c_i to use. Section 5 provides

[4] There are many reasons why it may desirable to obtain $I[y_i; c_i]$ rather than y_i. Among them are greater cost, greater reluctance of respondents to reveal y_i rather than $I[y_i; c_i]$, and a greater likelihood that observations on y_i will be contaminated by various survey response effects.

concluding remarks and suggests some possible extensions.

1.0 Relative Efficiency--Two Simple Examples

In this section we consider two simple examples, one with a single threshold and one with two thresholds. The role of the threshold(s) can be clearly grasped in these two simple cases and much of the intuition carries over to a more complex situation.

1.1 A Single Threshold Example

Consider a highly restricted form of the model in (1):

$$y_i = \mu + \varepsilon_i \ , \tag{2}$$

where ε is normally distributed, σ^2 is known, and instead of the systematic component being determined by $\alpha + \gamma x_i$, the observations have a common mean, μ. Assume further that the survey designer (or experimenter) has chosen to use only a single threshold, c. The problem the econometrician hoped the survey designer solved was to minimize, with respect to the choice of the c, the expression,

$$VAR(\hat{\mu} \mid I_n[y_i; c]) \ , \tag{3}$$

where $\hat{\mu}$ is a consistent estimator of μ and $I_n[y_i; c]$ is a random sample of size n containing observations on $I[y_i; c]$.

Given $I_n[y_i; c]$ and no covariates, the maximum likelihood estimator takes the form of a probit equation with only an intercept term as a regressor. The intercept term is an estimate of

$$\frac{\mu - c}{\sigma} \ , \tag{4}$$

and the asymptotic variance for the intercept term is given by,

$$\frac{\Phi\left[\frac{\mu - c}{\sigma}\right]\left[1 - \Phi\left[\frac{\mu - c}{\sigma}\right]\right]}{n\phi^2\left[\frac{\mu - c}{\sigma}\right]} \tag{5}$$

where ϕ is the standard normal probability function and Φ is the standard normal cumulative distribution function. Both of these functions will depend on the values of c chosen. It can be shown that the asymptotic variance (5) is minimized by setting $c = \mu$.

If a sample containing n observations on y_i is observed rather than $I_n[y_i; c]$, then the equivalent expression for the estimate of the intercept in the probit equation is $\frac{\bar{y} - c}{\sigma}$ where $\bar{y}$ is the maximum likelihood estimator of μ, i.e., the sample mean. Since σ is known, the asymptotic variance of this expression is simply:

$$\frac{1}{n} \, . \tag{6}$$

We will use the ratio of the asymptotic variance of these two estimators, given by

$$RE_p = \frac{VAR(\hat{\mu}_1 \mid y_i)}{VAR(\hat{\mu}_2 \mid I_n[y_i; c_i])} \, ,$$

as our measure of the relative efficiency of a particular discrete choice estimator. For the cases we consider this expression is known as the measure of Pitman asymptotic relative efficiency (Lehman, 1983). RE^p has a natural interpretation in that its reciprocal tells proportionately how much bigger the sample size of the estimator using $I_n[y_i; c_i]$ must be to obtain the same level of efficiency as the estimator based on a sample of size n containing y_i. For our simple example, RE^p is defined by the ratio of (6) to (5) with (5) being a function of the split between 0 and 1 responses that is implicitly defined by the choice of c. As one can see in Figure 1 this measure of relative efficiency is indeed maximized by setting $c = \mu$.

1.2 A Two Threshold Example

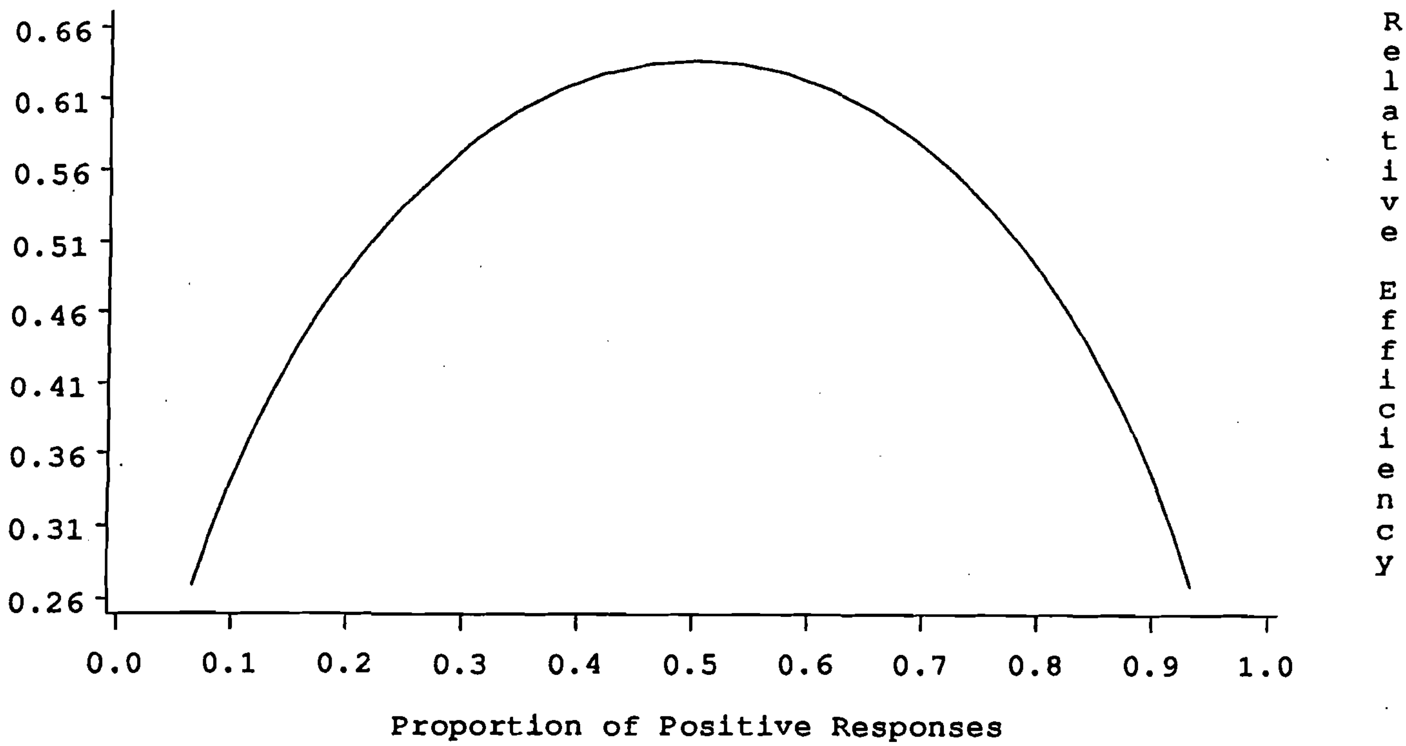
The disadvantage of using only a single threshold is that the location and scale parameters cannot be estimated separately. Let us maintain the assumptions of (2) except that now the researcher assigns half of the respondents to one threshold value, c_1 and half to another threshold value, c_2, where $c_1 \neq c_2$. Let p_i be the percent of respondents assigned to c_i for whom $I[y_i; c_i]$ equals 1. The probit equation can now be rewritten as,

$$\Phi^{-1}(p_i) = \alpha + \beta c_i \, . \tag{7}$$

Cameron and James (1987a) have shown that $\alpha \equiv \frac{\mu}{\sigma}$ and $\beta \equiv \frac{1}{\sigma}$ so that μ is estimated by $\frac{-\hat{\alpha}}{\hat{\beta}}$.

Figure 1

Relative Efficiency Of Discrete Data Estimator
Probit Model With Constant Threshold c; No Covariates



Theoretical Asymptotic Relative Efficiency of the Estimator for the Probit Intercept
(mean=0.5; standard deviation=1; sample size=1000)

This result is a direct consequence of the c_i being measured on the same scale as the y_i and having variation in both. It allows one to estimate the median (and other statistics) of a normal population and get asymptotic confidence limits in surveys that elicit an agent's economic preferences by means of the "take-it-or-leave-it" format. This approach has been applied in a straightforward fashion in contingent valuation about the willingness to pay for changes in the supply of environmental public goods.

The fiducial interval at the 95% nominal confidence level (defined in section 4.1) is minimized for $c_i = -0.372581\sigma + \mu$ and $c_i = 0.372581\sigma + \mu$ when the sample size is n=900. Such values result in the probit estimator for μ with the smallest variance when two distinct thresholds are used.

2. A Model with Covariates

Now consider the model in (1) again:

$$y_i = \alpha + \gamma x_i + \varepsilon_i \ , \tag{8}$$

where we assume that ε is normally distributed. Given a single threshold c, the probit intercept term is $\alpha^* = \frac{\alpha - c}{\sigma}$ and the probit regression coefficient is $\frac{\gamma}{\sigma}$. The statistic of interest is now $\frac{\gamma}{\sigma}$.

The MLE from the uncensored sample is $\frac{\hat{\gamma}_{ols}}{\hat{\sigma}_{ols}}$. The relative efficiency measure converges to:

$$\frac{1}{N}\left[\frac{1}{VAR(x)} + \frac{\beta^2}{2\sigma^2}\right] \bullet \left\{ E\left[\frac{\phi^2(z)}{\Phi(z)[1-\Phi(z)]}\right] \bullet VAR(x) + \left[COV\left[\frac{\phi^2(z)}{\Phi(z)[1-\Phi(z)]}, x^2\right] + \frac{\left[COV\left[\frac{\phi^2(z)}{\Phi(z)[1-\Phi(z)]}, x\right]\right]}{E\left[\frac{\phi^2(z)}{\Phi(z)[1-\Phi(z)]}\right]} - 2COV\left[\frac{\phi^2(z)}{\Phi(z)[1-\Phi(z)]}, x\right] E(x) \right\} , \tag{9}$$

where $z = \frac{(c-\alpha) + \gamma x}{\sigma}$. On average, the loss of relative efficiency is proportional to $p(1-p)$, where $p = \Phi(\frac{\alpha - c + \gamma x}{\sigma})$, plus several terms that depend on the x's, the covariance between the

x's and $\frac{\phi^2(z)}{p(1-p)}$, and the parameters in a complicated fashion.

Figure 2 plots the relative efficiency of the MLE for γ/σ from model (1), where x is a vector that has been generated as a standard normal random variable. Again, relative efficiency achieves its maximum in correspondence to the value of c such that the indicator variable takes a value of 1 with probability 50%. The maximum relative efficiency for γ is substantially lower (40%) than it is in the case of no covariates when there is only the intercept to estimate (64%). Even an 80/20% split on the indicator variable due to the choice of c results in relative efficiency falling to about 25% in our example. A 95/5% split results in a relative efficiency of only a little above 10%.

3.0 Optimal Designs.

3.1 An Optimality Result: One and Two-point Designs.

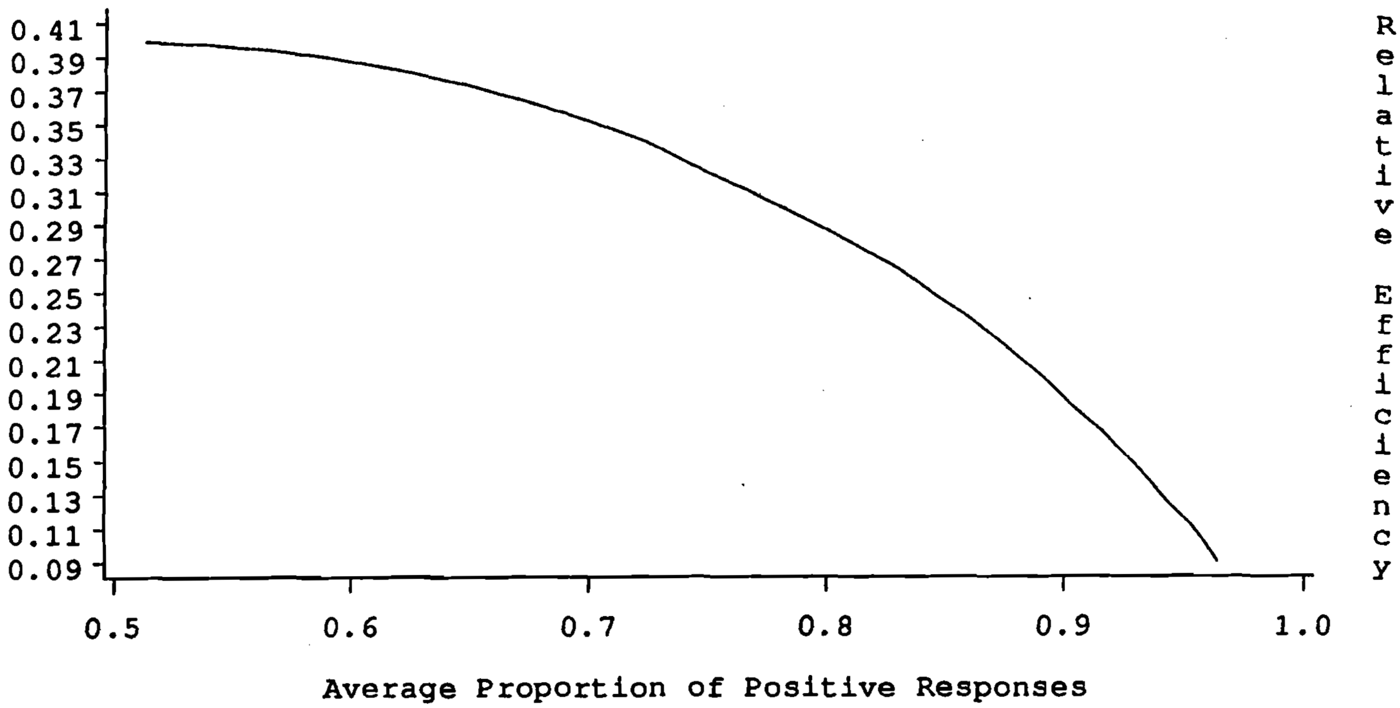
Given model (7), suppose the researcher can only observe the indicator variable $I[y_i; c_i]$ which takes value 1 if and only if y_i is greater than a specified threshold. The probability of recording 1 is $\Phi[\frac{\mu - c_i}{\sigma}]$; if we define $\alpha \equiv \frac{\mu}{\sigma}$ and $\beta \equiv \frac{-1}{\sigma}$, then it is $\Phi[\alpha + \beta c_i]$.

The statistic of interest is a certain quantile of the underlying normal distribution, which the researcher wants to estimate as efficiently as possible. In biostatistics, engineering, etc., the quantile of interest is denoted as ED100p (or LD100p), where ED stands for "effective dose" of a treatment just sufficient to observe the desired response (death, remission from a disease, failure of a mechanical part, etc.) in 100p% of the subjects (LD is short for "lethal dose"). Similarly, in labor economics, public economics, contingent valuation surveys and voting studies we are often interested in estimating the level of a certain economic variable in correspondence to which 100p% of the population undertakes a certain pattern of behavior.

The percentile of interest is expressed as $g(\alpha,\beta) = \frac{(\Phi^{-1}(p) - \alpha)}{\beta}$; its asymptotic variance is

Figure 2

Relative Efficiency Of Discrete Data Estimator
Probit Model With Constant Threshold c And One Normal Regressor



Relative Efficiency of the Probit Estimator for Gamma
(intercept=0.5; gamma=-1; standard deviation=1; sample size=500;
mean(x)=0; variance(x)=1; number of replications=15)

$$\begin{bmatrix} \frac{\partial g}{\partial \alpha} & \frac{\partial g}{\partial \beta} \end{bmatrix} \quad COV(\alpha, \beta) \quad \begin{bmatrix} \frac{\partial g}{\partial \alpha} \\ \frac{\partial g}{\partial \beta} \end{bmatrix}, \tag{10}$$

where $Cov(\alpha, \beta)$ is the asymptotic covariance matrix of the probit MLE for α and β. We want to find the optimal design for the experiment, that is, we want to find the thresholds c_i and the probability to put at each design point c_i that minimizes the asymptotic variance of the quantile. The solution to this unconstrained minimum problem (a special case of a c-optimal design; see Silvey, 1980) is provided by the following theorem:

THEOREM [WU, 1988]. Let $F(z)$ and $f(z)$ be the cdf and pdf of the underlying random variable $\frac{y-\mu}{\sigma}$. Define $w(z_i) \equiv \frac{f(z_i)}{F(z_i)(1-F(z_i))^{1/2}}$ and S the curve $w(z)(1,z)$. If $|w(z)z|$ converges to 0 as $z \to \infty$ and S is convex, then for $p < p_1$ and $p > p_2$ a two-point design is optimal, with design points $\frac{F^{-1}(p_1)-\alpha}{\sigma}$ and $\frac{F^{-1}(p_2)-\alpha}{\sigma}$ and probabilities α and $(1-\alpha)$ respectively, where α is a function of F. For $p_1 \le p \le p_2$ the optimal design is a one-point design, which puts probability 1 at $\frac{F^{-1}(p)-\alpha}{\sigma}$.

The benchmark probability levels p_1 and p_2 vary with the parametric family for $F(z)$. For the standard normal distribution p_1=.058 and p_2=.942.

Throughout this paper, we will assume the percentile of interest is the median $-\frac{\alpha}{\beta}$ (which coincides with the mean) of the random variable y. The optimal design for the normal distribution puts probability 1 at $\frac{\Phi^{-1}(0.5)-\alpha}{\beta} = -\frac{\alpha}{\beta}$.

However, as long as a single-threshold design is used, it is not possible to estimate the location parameter σ of the distribution; the one-threshold solution of the optimization problem is then useful only when the scale parameter is known and need not be estimated. The correct implementation of the one-threshold optimal design also requires knowledge of the very median (or, in general, the quantile of interest when $p \neq 0.5$) we want to find.

3.2 Role of Underlying Distribution

Table 1 displays the theoretical relative efficiency of the MLE for the median from the binary data model over a number of distributions $F(z)$ when the scale parameter is known.

TABLE 1

$F(y_i)$	LINK FUNCTION	RELATIVE EFFICIENCY
normal	probit	0.6366
logistic	logit	0.7500
smallest extreme value	log-log	0.4804
largest extreme value	complementary log-log	0.4804

At least two of the distributions we have considered for Table 1 can be shown to be special cases of a more general parametric family (Aranda-Ordaz, 1981): $F(z)=1-(1+\lambda exp(z))^{\frac{-1}{\lambda}}$ for $\lambda exp(z) > -1$, where z is a standardized random variable and λ is a shape parameter. In particular, for $\lambda = 0$, the distribution reduces to the extreme value distribution (which corresponds to the complementary log-log link function); for $\lambda = 1$, it reduces to the logistic distribution (logit link function). For this family of distributions the relative efficiency for the median in a single-threshold situation can be expressed as:

$$\frac{\left[\frac{\lambda}{1+\lambda}\right]\left[E\left[\frac{\lambda exp(z)}{[1+\lambda exp(z)]^2}\right]\right]^{-1}}{\frac{0.25}{\left[\frac{1}{2\lambda}-\frac{1}{\lambda}\left[\frac{1}{2}\right]^{1+\lambda}\right]^2}} \qquad (11)$$

Figure 3 traces out the relative efficiency as a function of the shape parameter λ. The relative efficiency (76%) is maximized at λ=1.16.

Another class of models that have been proposed (Prentice, 1976) for dose-response relationships is:

$$p = \frac{1}{B(m_1, m_2)} \int_{-\infty}^{z} exp(m_1 x)(1+exp(x))^{-(m_1+m_2)}\, dx \qquad (12)$$

(Prentice, 1976) where $B(m_1, m_2)$ is the beta function. $m_1 = m_2 = 1$ gives the logit model, and, as $m_1 \rightarrow \infty$ and $m_2 \rightarrow \infty$, p converges to the probit model. A plot similar to that in Figure 3 can be calculated for this family of distributions.

4. Optimal Experiment Designs with Multiple Thresholds.

4.1 Fiducial Confidence Limits and *d*-optimality.

In most real-life situations, when the researcher wishes to estimate both the scale and the location parameter, a one-point design approach loses its appeal. However, the basic problem with a multiple-point design, where the desired objective is to minimize the variance of the estimate of a particular percentile, is that unconstrained designs tend to degenerate back into a one-threshold design. One can chose a different objective function such as one which puts some weight on a good estimate of the scale parameter or impose the constraints such as ensuring that there are thresholds placed on each side of the percentile of interest, that there is some minimum distance between thresholds, and/or that there is some minimum number of observations assigned to each threshold.

Where we are interested in the mean/median of the underlying normal distribution, Finney (1978) proposes to find the design that minimizes the length of the fiducial interval around the mean at the desired nominal level of confidence. The fiducial interval for the probit estimate $\hat{\mu}$ for the mean of the normal cdf is slightly different from the expression that makes use of the asymptotic variance of the estimate for the mean (as in section 2), because it is computed using Fieller's theorem, which gives an expression for the confidence limits for the ratio of mean values of two normally distributed estimators at a given confidence level. Such confidence limits, which are function of the thresholds c_i's can be expressed as:

$$\hat{\mu} + \left[\frac{(\hat{\mu} - z)g}{(1-g)}\right] \pm \frac{tI^{1/2}}{\hat{\beta}(1-g)} \tag{13}$$

for $g < 1$, where

$$I = \frac{(1-g)}{\sum n_i w_i} + \frac{w^2}{\sum n_i w_i (z_i - w)^2} \ ,$$

$$z_i = \alpha + \beta c_i \ ; \ w_i = \frac{\phi^2(z_i)}{\Phi(y_i)[1-\Phi(y_i)]} \ ,$$

$$z = \frac{\sum n_i w_i c_i}{\sum n_i w_i} \ ; \ w = \frac{\sum n_i w_i z_i}{\sum n_i w_i} \ ,$$

$$g = \frac{t^2}{\sum n_i w_i (z_i - w)^2} \ ,$$

and t is a standard normal deviate. For $g = 1$ the fiducial limits coincide with the regular confidence bounds.

While both minimization of the asymptotic variance of the median and the minimization of the length of the fiducial interval are special cases of *c*-optimal design (see Silvey, 1980, for a definition), Abdelbasit and Plackett (1983) propose to resort to the criterion of *d*-optimal design. In short, a *d*-optimal design (see Silvey, 1980) attempts to minimize the "size" of the asymptotic covariance matrix of the estimators for α and β by making the log of the determinant of information matrix as large as possible. Intuitively, we expect a design method that aims at minimizing the variance of the estimate for a specific quantile of the distribution to be superior, in correspondence of that quantile, to a design that tries to produce "good" estimates over the whole range of values of p, where p defines the percentile of the distribution. On the other hand, a *d*-optimal design should in principle do a better all-round job, so that the estimate for each given percentile may not be the most efficient (a minimum-variance design being more efficient), but as we move from one percentile to another there should not be any substantial loss of efficiency. Such loss of efficiency is most likely to occur if we employ the experiment design that is optimal for minimizing the variance of the $100p_1$ percentile to estimate the $100p_2$ percentile, where p_2 and p_1 differ by a sufficiently large amount (see Figure 4).

Once we constrain the number of design points to be strictly greater than 1, as we will in the constrained optimization problems for the fiducial method and the *d*-optimal design, the optimal design points will be on the sides of the median . For a given number of design points, we expect the design points of the fiducial method to be closer to the origin than the *d*-optimal design points.

The log of the determinant of the information matrix for α and β is:

$$\left[\sum_{i=1}^{n} \frac{\phi^2(\alpha+\beta c_i)}{\Phi(\alpha+\beta c_i)[1-\Phi(\alpha+\beta c_i)]} c_i^2\right]\left[\sum_{i=1}^{n} \frac{\phi^2(\alpha+\beta c_i)}{\Phi(\alpha+\beta c_i)[1-\Phi(\alpha+\beta c_i)]}\right] - \left[\sum_{i=1}^{n} \frac{\phi^2(\alpha+\beta c_i)}{\Phi(\alpha+\beta c_i)[1-\Phi(\alpha+\beta c_i)]} c_i\right]^2 . \qquad (14)$$

This quantity depends on the unknown parameters α and β, as does the expression for the length of the fiducial interval, so it is necessary to have some initial estimates for the parameters if the researcher has to come up with actual design points for the experiment.

Three different approaches have been suggested and tested in the optimal design literature:

(i) One-stage experiments, whereby initial guesses about the parameters are available and plugged into the expression for the objective function to optimize with respect to the choice of the design points;

(ii) Sequential experiments, whereby the experiment is divided into stages, and the final estimates from each stage are used as the initial guesses for the parameters in the next stage. Each step produces estimates that are more efficient.

Finally, the researcher may decide to express the level of a priori confidence on the values of the parameters by means of a prior distribution. This implies (iii) a bayesian approach.

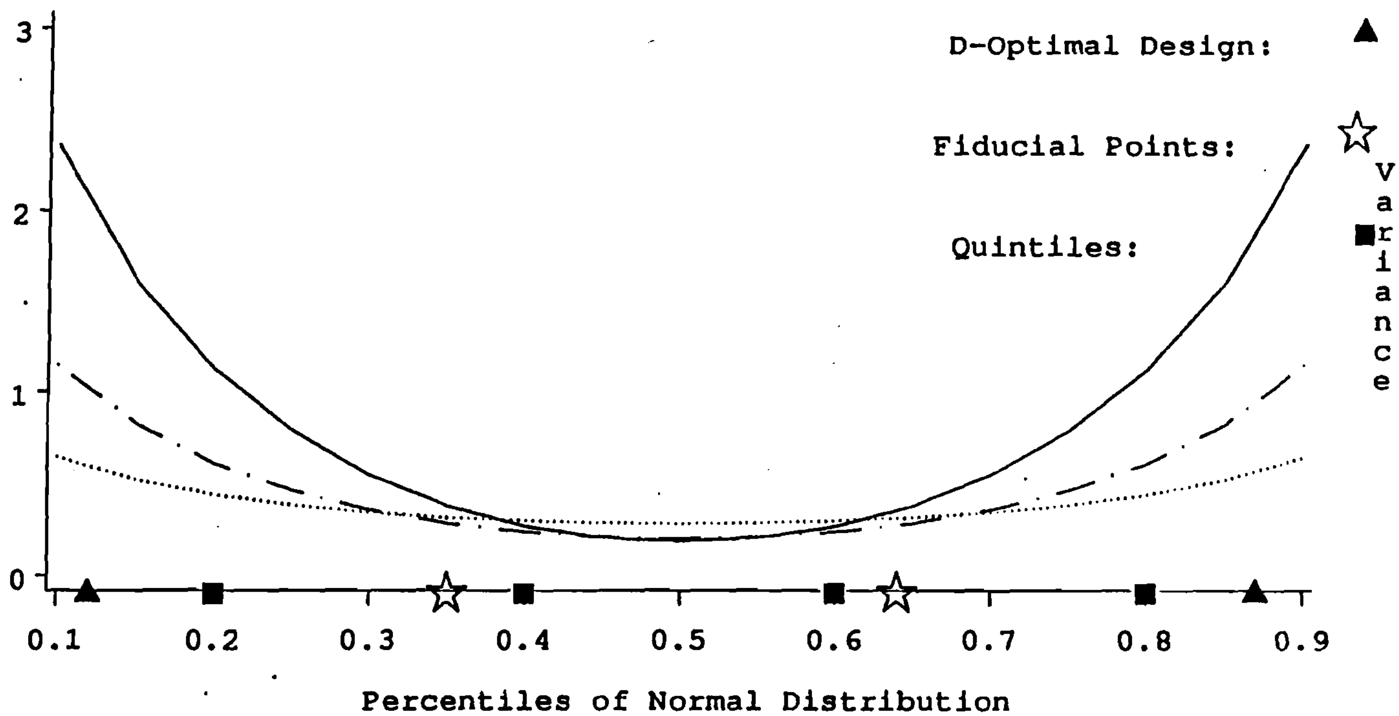
4.2 Construction of Experiment Designs.

The performances of the fiducial method and the *d*-optimal design are compared in a one-stage type of experiment to see which one gives the more efficient estimates for the mean; robustness in presence of bad initial guesses about the parameters is also investigated.

It is standard survey procedure, as well as standard experimental practice in the biological sciences, to divide the subjects uniformly among the available design points, so we will assume that, with sample size n and number of design points k both a priori given to the researcher, each design point is randomly assigned $\frac{n}{k}$ observations.

Figure 4

Absolute Efficiency of Discrete Data Estimator for Percentiles
Designs are Optimized for Estimating p=0.5 Using a Max. of Four Threshold Level



Sample Size=900; Mean=10; Standard Deviation=10
Legend: Solid Line: Fiducial Method; • • • : D-optimal Design; -•-•-•: Quintiles

The d-optimal design is, then, symmetrical with respect to the median itself and the design points are evenly spaced; applying these latter restrictions to the fiducial method (the variance of the MLE for the median, as it is computed from the probit equation, would become arbitrarily large when the design points are placed on only one tail of the normal distribution as they are farther and farther away from the median), the expression for the quantity to maximize in the fiducial interval case simplifies to:

$$\frac{k}{t^2}\left[\left[1-\frac{t^2k}{n\sum_{j=1}^{k} b_j z_j^2}\right]\left[\sum_{j=1}^{k} b_j\right]\right]^{-1} \tag{15}$$

where $b_j = \alpha + \beta c_j$.

Both the d-optimal design and the fiducial method design reduce to a two-point design for even k and a three-point design for odd k; this result (see Finney, 1978; Abdelbasit and Plackett, 1983) is a useful simplification that makes the survey or the experiment easier to administer. Furthermore, given the assumption that the subjects are evenly divided among the thresholds, the determinant of the information matrix (which is a meaningful quantity in the case of the d-optimal design) simplifies to an expression such that the d-optimal points do not depend on the sample size n. For the fiducial method, though, the optimal design points do depend on the sample size.

For n=900, Table 3 reports the optimal design points for selected values of the number of thresholds k. For even k, the designs (fiducial method and d-optimal) are *the* two-point designs for each respective method, while for odd k the designs are three-point designs (one of these points is the median), but not necessarily the same design for different k's. The table also shows that the thresholds are closer to the median (0 in normal standard units, that is, when we take the deviation from the mean of the thresholds expressed in the same scale as the y_i's and rescale by the standard deviation) with the fiducial method, while the d-optimal thresholds tends to put them further away on the tails. Notice that as k gets larger, the three-point design appears to take more and more weight away from the median to redistribute it between the other two points, which in fact get closer to the median. For large k (k odd) we intuitively expect the design to converge to a two-point design. The corresponding theoretical relative efficiency (i.e. in correspondence of the correct values of the parameters) is 0.6144 for the fiducial method (for *any* k: the relative efficiencies computed for different k's are identical up to the fifth decimal place); for the *d*-optimal design the theoretical relative efficiency is 0.4630 for an even number of thresholds, 0.4366 for k=3, 0.4149 for k=5, and 0.4036 for k=9. As long as the parameters are known exactly a priori, increasing the number of thresholds for a *d*-optimal design worsens the performance of the probit estimator in terms of relative efficiency, and certainly does not improve the relative efficiency for the fiducial method.

TABLE 3
Design points for n=900 and selected k's (in standard normal units).

Finney's fiducial method	k=2	k=3	k=4	k=5	k=6	k=9
	450 units at -0.372581	300 units at -0.458768	450 units at -0.372581	360 units at -0.417678	450 units at -0.372581	400 units at -0.395715
	450 units at 0.372581	300 units at 0	450 units at 0.372581	180 units at 0	450 units at 0.372581	100 units at 0
		300 units at 0.458768		360 units at 0.417678		400 units at 0.395715

D-optimal design method	k=2	k=3	k=4	k=5	k=6	k=9
	450 units at -1.138101	300 units at -1.298080	450 units at -1.138101	360 units at -1.231471	450 units at -1.138101	400 units at -1.188696
	450 units at 1.138101	300 units at 0	450 units at 1.138101	180 units at 0	450 units at 1.138101	100 units at 0
		300 units at 1.298080		360 units at 1.231471		400 units at 1.188696

TABLE 3 (CONTINUED)
Design points for n=900 and selected k's (in standard normal units).

Percentiles	k=2	k=3	k=4	k=5	k=6	k=9
	450 units at -0.431	300 units at -0.675	225 units at -0.84	180 units at -0.967	150 units at -1.07	100 units at -1.28
	450 units at 0.431	300 units at 0	225 units at -0.253	180 units at -0.43	150 units at -0.566	100 units at -0.84
		300 units at 0.675	225 units at 0.253	180 units at 0	150 units at -0.18	100 units at -0.53
			225 units at 0.84	180 units at 0.43	150 units at 0.18	100 units at -0.25
				180 units at 0.967	150 units at 0.566	100 units at 0
					150 units at 1.07	100 units at 0.25
						100 units at 0.53
						100 units at .84
						100 units at 1.28

As n increases, relative efficiency increases for the fiducial method: for n=360,000 and n=720,000 the relative efficiency is 0.6350 and 0.6355, which are very close to the value of the relative efficiency for the single-threshold design (0.6366) under ideal conditions.

In order to establish the ranking of the alternative design methods in presence of uncertainty about the true values of the parameters, we propose a third method based on equally spaced percentiles of the normal distribution. The percentiles of the distribution are defined as follows: when a k-point design is used, we find the points that cumulate $\frac{j}{k+1}$ percent of the normal distribution, for j=1, 2, ..., k. The percentiles do not have specific properties, and are not the solution of a well-defined optimization problem: they are just a common-sense approach that, among the other things, allow us to evaluate the effect of increasing the number of design points when the true values of the parameters are not known exactly. The percentiles are displayed in Table 3 for selected k's. The theoretical relative efficiency for a percentile-type design is very close to that of the fiducial points for k=2 and k=3 (0.5942 and 0.5712 respectively). For $k > 3$ the relative efficiency oscillates between 0.52 and 0.53.

4.3 The Relative Efficiency of the Alternative Designs.

We generated 100 replications of samples of 900 independent observations from a normal random variable with mean and standard deviation equal to 10, and then applied the thresholds corresponding to the d-optimal design, the fiducial method at the 95% confidence level and the appropriate percentile as described in Section 3.2 for k=2, 3, 4, 5, 6, and 9.

The first series of replications assumed correct knowledge of the parameters; the others introduced biased initial estimates for the mean and the variance. Such biases affect the appropriate shifting and rescaling of the design points that are given in standard units in Table 3.

For each sample, the sample mean of the uncensored data and its estimated variance were computed. For each k, after the optimal thresholds for each method were used to censor the sample, the intercept and the regression parameter of the probit model, and their covariance matrix were estimated; the estimates for the median and its variance were computed. Finally the relative efficiency was computed. Averages over the replications were taken to study the expected behavior of the above mentioned statistics.

We considered initial estimates that overstate the true parameters (by 25%, 50% and 75%) and understate the true parameters (by 25%, 50%, and 75%), as shown in Table 4.

The mean, the variance, and both parameters simultaneously were assigned poor initial estimates, thus generating 48 different cases. We will limit our comments to the experiments with even k's.

TABLE 4

Initial Estimates for Mean and Variance

BIAS	ESTIMATED MEAN	ESTIMATED VARIANCE
-75%	2.5	25
-50%	5.0	50
-25%	7.5	75
TRUE	10.0	100
+25%	12.5	125
+50%	15.0	150
+75%	17.5	175

In order to get the thresholds to be expressed in the same scale as the underlying y_i we need to know the true mean and variance. Of course in general the mean and the variance are not known and we collect the data and proceed to estimate these parameters because they are unknown. We use the initial estimates for the mean and the variance as tabulated above to construct the thresholds, and then, once the dependent variable for each subject has been generated accordingly, we estimate the parameters of the underlying distribution by the method of ML. When the correct values of the parameters are used at the preliminary stage of the survey (or experiment) to find the thresholds, both the fiducial method and the *d*-optimal designs give final estimates for the variance and the relative efficiency that are close, at least on average, to the theoretical values. Using the final estimates for the parameters, instead of the theoretical values, when we compute the variances produces some degree of sampling variation of the statistics of interest. For the *d*-optimal design, there appears to be a slightly larger discrepancy between theoretical and sample relative efficiency (the average over the replications being only 0.39 versus the theoretical 0.46).

When poor initial values are used, the relative efficiencies for the *d*-optimal, the fiducial method and the percentile design are all symmetric around the true mean, in the sense that, holding the guess for the variance fixed, overestimating or underestimating the mean by the same proportion gives on average the same relative efficiency and variance for the estimated mean. Therefore it suffices to look at the average mean relative efficiency tabulated by absolute relative bias of the mean for every value of the standard deviation (Table 5).

However, there is asymmetry around the true variance; holding the guess for the mean fixed, overstating the variance will result in a different average relative efficiency than that of the experiment that understates the variance. This pattern can be seen in Figures 5, 6, 7 and 8.

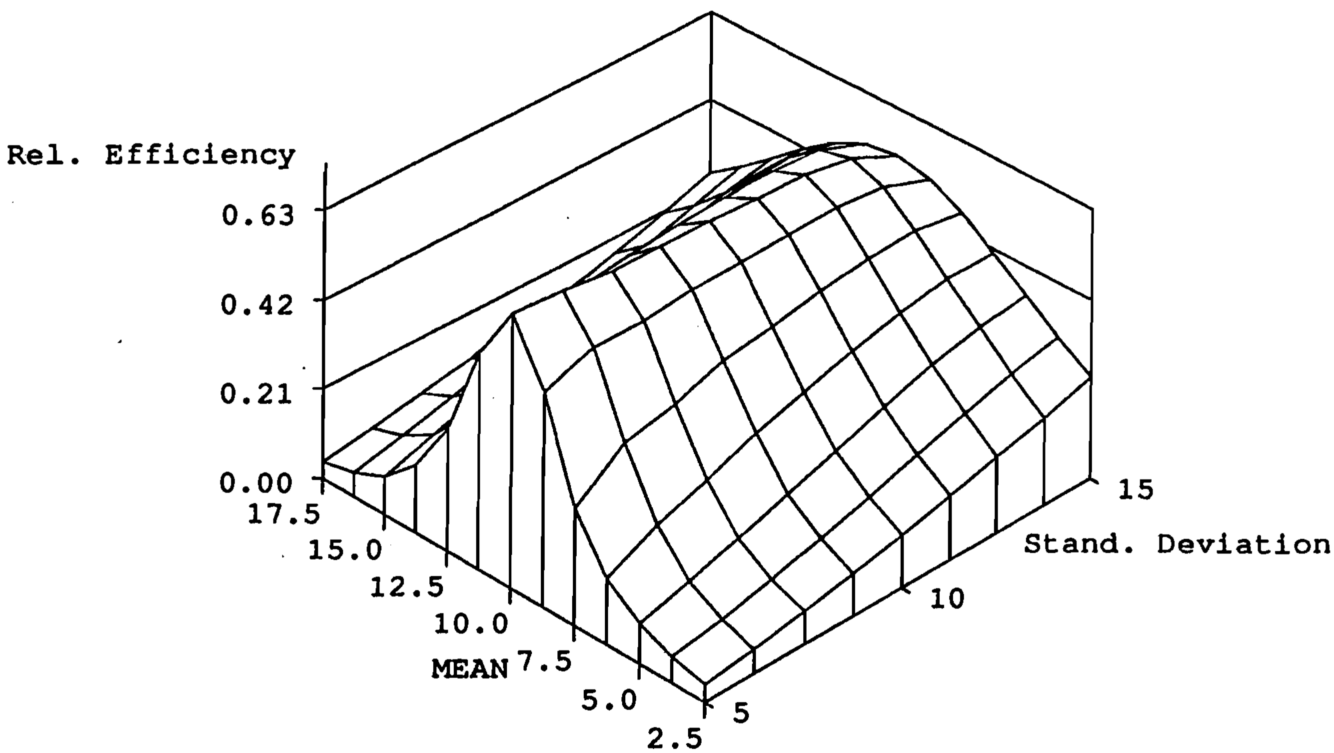
The results are exactly the opposite for the *d*-optimal design and the fiducial method so that, up to plus or minus 50% bias of the mean, the methods are almost mirrorlike images of each other with respect to the plane that goes through the true variance and is orthogonal to the (mean, variance) plane in the three-dimensional space of Figures 5, 6, 7, 8.

In general, when the mean is guessed correctly, the fiducial method is very robust to bad guesses about the variance (the relative efficiency is around 0.60), but the relative efficiency drops sharply as soon as the guesses for the mean depart from the true value.

For a small bias for the estimated mean (25%, so that the guess is either 7.5 or 12.5) the fiducial method yields relative efficiency as high as 0.48 for overestimated variance and as low

Figure 5

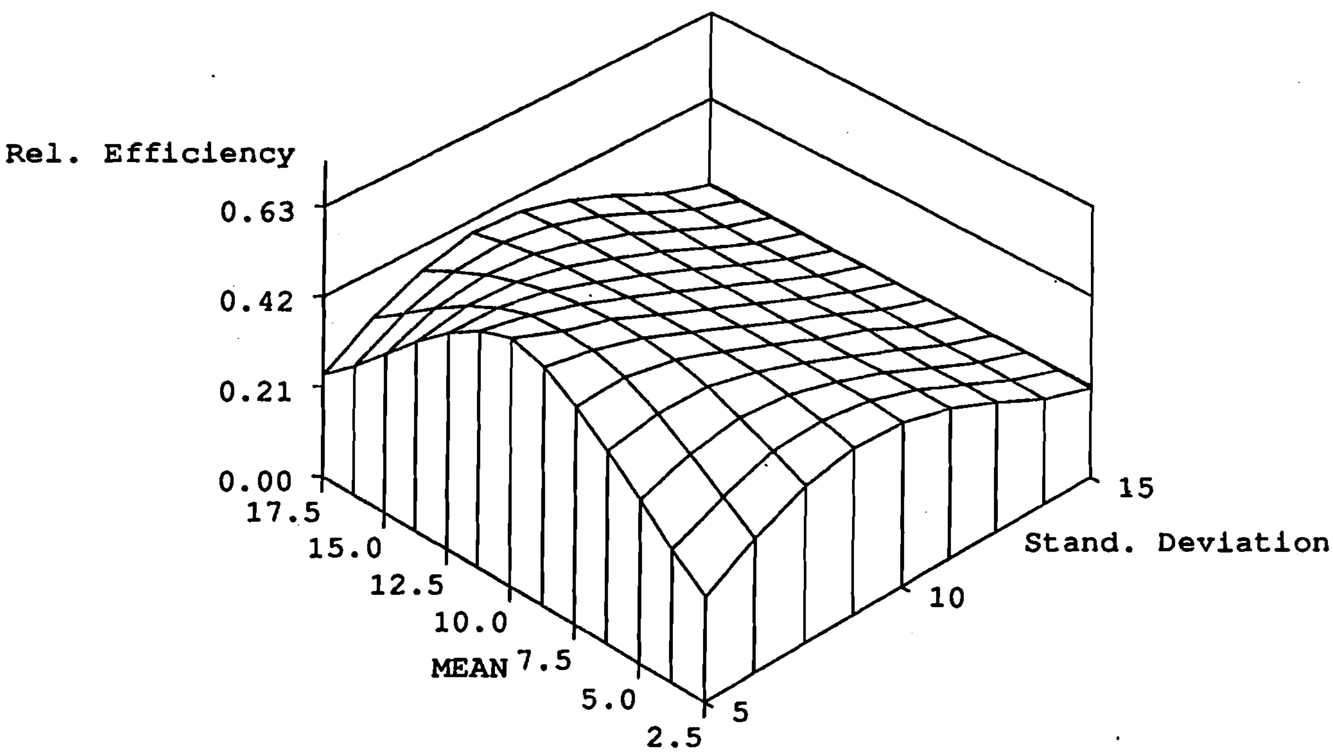
Relative Efficiency Of Discrete Data Estimator
Two-point Fiducial Method (95% confidence level)



Average Relative Efficiencies Over The Replications

Figure 6

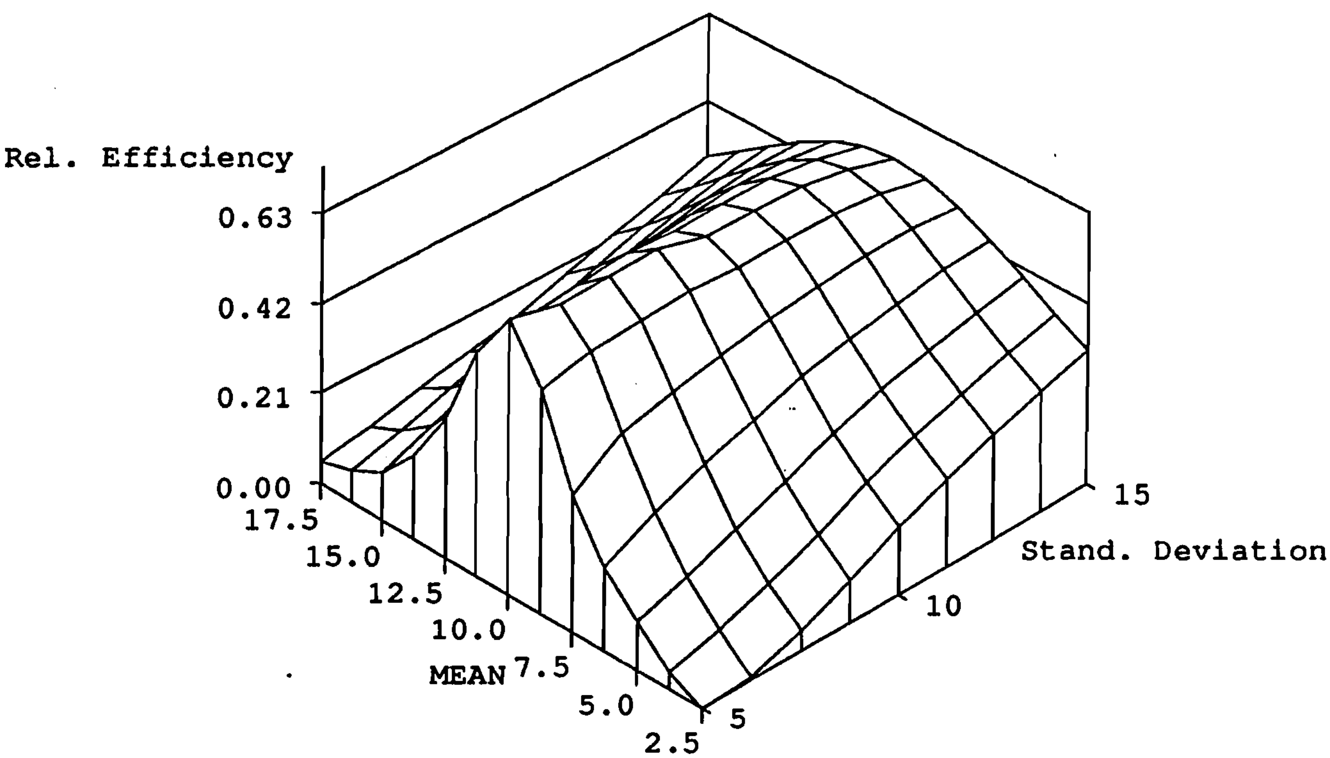
Relative Efficiency Of Discrete Data Estimator
Two-point D-optimal Design



Average Relative Efficiencies Over The Replications

Figure 7

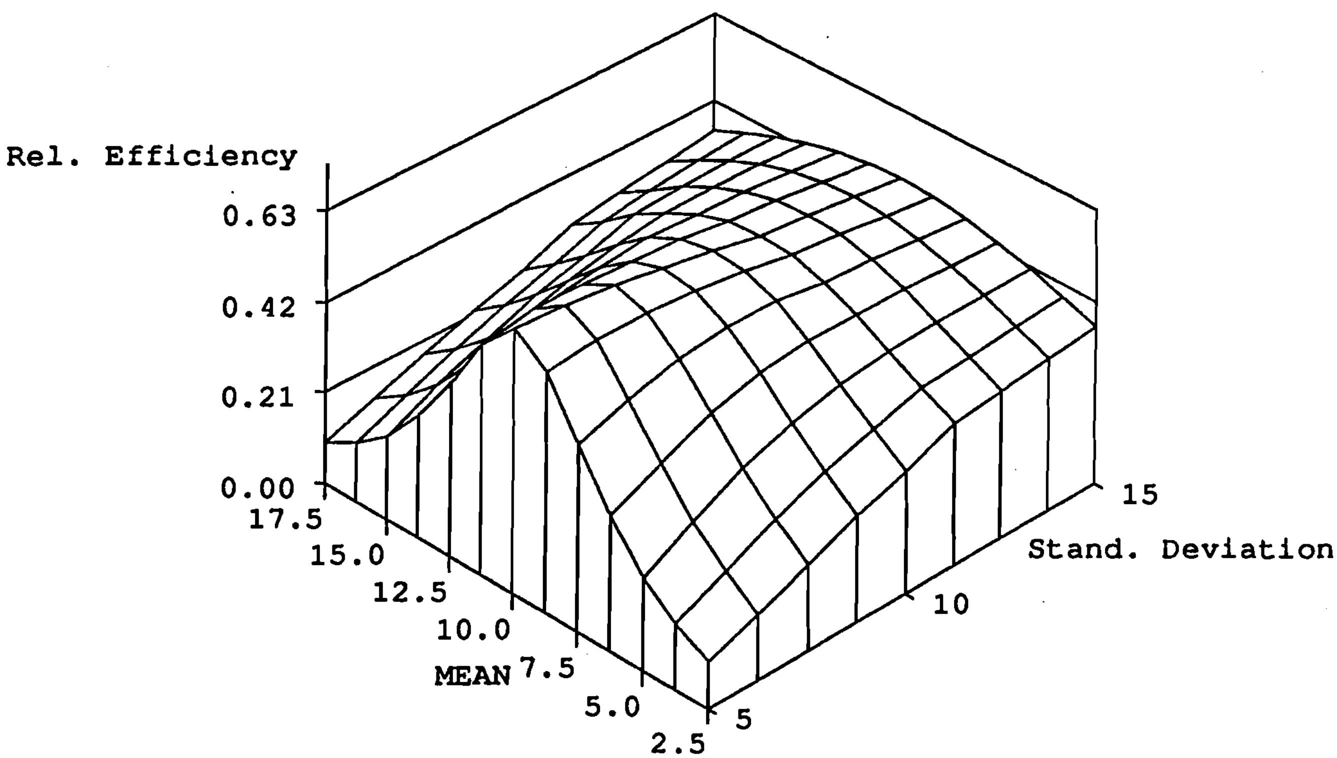
Relative Efficiency Of Discrete Data Estimator
33% Percentiles



Average Relative Efficiencies Over The Replications

Figure 8

Relative Efficiency Of Discrete Data Estimator
Quintiles



Average Relative Efficiencies Over The Replications

as 0.26 for grossly underestimated variance, hence we are better off by making an overstated guess for the variance; with the *d*-optimal design, underestimating the variance produces a relative efficiency of about 0.49 while overestimating it will lower the efficiency to 0.26.

Similarly, for a 50% bias of the mean estimate, allowing for higher uncertainty on the distribution (larger variance) improves the performance of the fiducial design and worsens that of the *d*-optimal design (for σ =13.32, the average relative efficiencies are 0.32 and 0.26 for the fiducial method and the *d*-optimal design), while lowering it has the opposite effect (0.04 and 0.36 respectively).

Abdelbasit and Plackett (1983) report findings of a similar nature when they investigate the robustness of Finney's fiducial limits and the *d*-optimal design to poor initial estimates. The criterion they adopt for efficiency is, for each method, the ratio of the objective function evaluated at the initial estimates over its value in correspondence of the final estimates. The direction of the impact of bad initial estimates they observe confirms ours, although we judge efficiency by a different criterion, the Pitman relative efficiency.

In short, the fiducial method appears to be the best when the mean is guessed correctly (no matter how bad the initial estimate for the variance is) and when, in presence of a moderate bias of the mean, the variance is overstated, while a *d*-optimal design performs better, for a poor initial estimate for the mean, when the variance is understated.

For initial estimates for the mean that are biased by 75% the *d*-optimal design is superior at all levels of the initial value for the variance.[5] With a *d*-optimal design, the profile for the average relative efficiency is quite flat and stable (see Figure 4). There is never a dramatic loss of relative efficiency, but the peak is also much lower than that with the fiducial method design. At best, we would need to double the size of the sample to attain a given level of precision of the estimate for the mean using a probit model.

[5] The fiducial points produce relative efficiencies that range between 0.04 (for initial σ=5) and 0.19 (for σ=13.32), the *d*-optimal points between 0.26 (σ=13.32) and 0.39 (σ=8.66).

Looking back at Table 3, we conclude that the poor performance of the fiducial method for sufficiently large biases of the mean is connected with the location of the design points. The *d*-optimal design places its points reasonably far away from the median of the normal distribution so that it picks the curvature of the density better. Finney's points are very close to the median, so while on the one hand they are much less affected by wrong initial estimates for the variance, on the other hand they are obviously very sensitive to the wrong choice of the median. The fiducial points do better than the *d*-optimal points for the correct value of the median when the variance is understated, because they get placed closer to the mean; when a moderate bias affects the mean, overstating the variance will place the fiducial points away form the wrong mean and may improve the performance of the design.

The *d*-optimal design always produces the lowest variances of the estimated parameters of the probit model, $\hat{\alpha}$ and $\hat{\beta}$, and their covariance. The fiducial method achieves better results on the variance of their ratio due to the impact of the covariance (since the covariance is negative, a covariance that is higher in absolute value reduces the variance of the probit $\hat{\mu}$).

For k=2 the percentiles are not very different from the fiducial points (Figure 7), but for k=4, the percentiles exhibit interesting properties. They are inferior to the fiducial points but better than the *d*-optimal design when the mean is known exactly; when the estimate for the mean has only a small bias they do just as well as the fiducial points if the variance is overstated and as well as the *d*-optimal points if the variance is understated. For 50% bias the superiority of the percentiles is not clear-cut: they do better than the fiducial method for σ greater than the true value but the *d*-optimal design is again better for understated σ. At 75% bias, the *d*-optimal design is definitely superior to the others, but the percentiles outperform the fiducial points. For k=6 and k=8, with a 75% bias of the mean, the percentiles do at least as well as the *d*-optimal design for overstated variance, while at 25% and 50% bias the ranking of the methods established at k=4 still holds.

TABLE 5

Average Relative Efficiency by Size of the Bias of the Mean for given Initial Guess for the Standard Deviation

Fiducial Method (k even).

BIAS OF THE MEAN.

σ	TRUE	25%	50%	75%
5.00	0.6289910	0.2791580	0.0877610	0.0392025
7.07	0.6126114	0.3602740	0.1457214	0.0679250
8.66	0.6057322	0.4163159	0.1942859	0.0951939
10.00	0.6031829	0.4412719	0.2342360	0.1318429
11.80	0.5949324	0.4697909	0.2839385	0.1572778
12.25	0.5919563	0.4754225	0.2963593	0.1672980
13.32	0.5825540	0.4891099	0.3234109	0.1908238

D-optimal Design (k even)

BIAS OF THE MEAN.

σ	TRUE	25%	50%	75%
5.00	0.5661480	0.4946159	0.3658009	0.3012762
7.07	0.4816706	0.4846736	0.4250892	0.3437231
8.66	0.4360513	0.4362835	0.4214986	0.3826452
10.00	0.3908402	0.3896147	0.3859160	0.3777427
11.80	0.3205690	0.3207494	0.3220435	0.3270518
12.25	0.3032441	0.3030827	0.3042571	0.3088714
13.32	0.2630080	0.2621345	0.2609878	0.2604021

33%-percentiles (k=2).

BIAS OF THE MEAN.

σ	TRUE	25%	50%	75%
5.00	0.6255566	0.3096907	0.1077331	0.0487906
7.07	0.6058384	0.4015778	0.1788827	0.0872073
8.66	0.6053828	0.4414112	0.2341617	0.1200527
10.00	0.5947947	0.4676236	0.2788517	0.1524575
11.80	0.5784141	0.4875116	0.3301337	0.2006705
12.25	0.5743022	0.4907701	0.3425872	0.2119675
13.32	0.5634338	0.4948203	0.3687846	0.2397943

Quintiles (k=4).

BIAS OF THE MEAN.

σ	TRUE	25%	50%	75%
5.00	0.6023773	0.4056219	0.1972386	0.0988890
7.07	0.5882651	0.4681341	0.2947193	0.1684757
8.66	0.5580085	0.4910441	0.3478878	0.2263948
10.00	0.5376189	0.4951301	0.3786436	0.2653765
11.80	0.5196822	0.4863396	0.4001910	0.2935609
12.25	0.5043401	0.4791369	0.4078903	0.3173975
13.32	0.4882451	0.4677250	0.4130149	0.3336771

14%-percentiles (k=6).				
BIAS OF THE MEAN.				
σ	TRUE	25%	50%	75%
5.00	0.6017511	0.4167612	0.2155374	0.1068886
7.07	0.5789509	0.4764025	0.3055655	0.1856032
8.66	0.5539752	0.4920061	0.3618820	0.2395791
10.00	0.5358414	0.4895850	0.3913631	0.2782665
11.80	0.5147538	0.4824710	0.4027312	0.3082509
12.25	0.4969901	0.4727377	0.4106255	0.3273440
13.32	0.4794147	0.4611243	0.4115908	0.3406947

9%-percentiles (k=8).

BIAS OF THE MEAN.

σ	TRUE	25%	50%	75%
5.00	0.5928510	0.4398145	0.2348644	0.1210007
7.07	0.5634282	0.4837353	0.3319495	0.2030062
8.66	0.5382317	0.4899203	0.3758122	0.2634850
10.00	0.5148922	0.4817124	0.3991905	0.2977778
11.80	0.4945306	0.4705580	0.4057034	0.3230235
12.25	0.4747422	0.4569732	0.4081252	0.3379378
13.32	0.4569439	0.4429341	0.4024695	0.3446838

5. Concluding Remarks and Suggested Extensions

We have considered the question of what is the loss in efficiency from using $I_n[y_i; c_i]$ as the dependent variable rather than y_i and found that it depends on the choice of the c_i and the underlying distribution for ε. At most it is a little over 75% and for the normal it is less $\frac{2}{\pi}$ or about 64%. This means that significantly larger data sets are needed when trying to estimate, at a given level of precision, parameters in a linear model using binary discrete data. Poor choices of c_i can result in dramatically lower relative efficiencies. For example, to get the same level of efficiency in estimating the mean/median with $I_n[y_i; c_i]$ as you would get with a sample of 1000 y_i's, one would need over 4000 observations if c were chosen so that 95% of the observations had had $I_n[y_i; c_i]$ equal to 1 or 0.

Given the 62% relative efficiency of an optimal design, a better choice of c could have saved over 2000 observations. If reasonably sure of the values of the parameters then the choice of the c_i is relatively straightforward. One can chose a method based on minimizing confidence intervals (Finney's fiducial method) or on maximizing information (*d*-optimal design).

Uncertainty about the true parameters suggests a Bayesian approach. Such an approach has been examined by Tsutakawa (1972; 1980). In particular, he assumed a normal prior for the location parameter and and a gamma prior for the scale parameter. The design minimized the prior expectation of the posterior variance of the estimate of a given ED100p. The approach leads to more values of c_i spaced farther apart than does the fiducial method when there is substantial uncertainty about the parameters. Our initial work suggests that for diffuse priors, the resulting design looks much like the quantile method developed in this paper.

We believe a more interesting approach is the sequential one. This is what is done consistent with the way that many large surveys and experiments are done: a series of pretests and/or pilot studies are run leading up to the main survey or experiment. In sequential experiments, the final estimates from each stage are used as the initial estimates at the next stage when the thresholds are found. If it were possible to increase the sample indefinitely, we would terminate the procedure when no further gain in efficiency is attained by doing one more step. However, for most experiments it is assumed that the sample size is given and the sample units are divided (often uniformly) among a preassigned number of stages. Work in this area (Ford and Silvey, 1980; Wetherhill, 1975) suggests that sequential estimates of the parameters converge quickly (i.e in a small number of stages) to the true values under conditions likely to be of interest to economic researchers.

Another useful direction for future work is to look at discrete choice models with higher informational content. One can do this by increasing the number of choices so that a response falls into an interval bounded by two thresholds. The more interesting variants of this approach make the choice of the second threshold conditional on the response to an initial binary discrete choice question. The choice of the threshold levels may become quite complex in this situation. Models of this sort can be analyzed using interval censored survival analysis techniques.

Our work may also be relevant to a new controversy in economics. Tversky, Slovic, and Kahneman (forthcoming) claim that a much more serious variant of the well known preference reversal phenomena exists. They provide empirical evidence which supports the notion that agents make different choices when asked to respond in a matching (i.e., give an answer on a continuous scale) mode as oppose to a choice (i.e., give a yes or no answer) mode. This is troubling because both response modes should be driven by the same underlying preferences and should obtain their results without invoking any uncertainty or probabilities. The work in this paper would allow this debate to be cast in terms of the information conveyed in a particular response. For instance, Tversky, Slovic, and Kahneman state that the choice mode is easier for agents to use in decision making. Our work would allow that statement to be made more precise by quantifying how much less information is conveyed by the choice mode response. It should also make obvious the fact that the choice mode response can be made easier or harder in an informational sense by the choice of the threshold and it also suggests that comparing the behavior indicated by matching and choice mode responses is not straightforward, particularly, if independent sources of random error are allowed to influence the two responses.

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EXISTENCE VALUE AND RESOURCE EVALUATION

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Possible incorporation of existence values into resource valuation studies raises questions on two levels. First, there are a host of theoretical and conceptual questions. For example, are there reasons to rule out the "existence" of existence values on a priori grounds. If not, then how should existence values be integrated with welfare theory? How would it be best to characterize existence for purposes of theoretical analysis? What is the role of irreversibility? What role should existence value play in benefit-cost analyses of public projects and policies and in other applications of welfare theory such as resource damage assessments? Second, assuming existence values can be dealt with in a satisfactory way from a theoretical point of view, can they be measured? Existence, as it has been defined in the literature, lacks a complete link through weak complementarity with market commodities. Market data cannot be used in estimation. Thus, the only available method of estimation is contingent valuation. Can contingent valuation yield existence value estimates that are sufficiently accurate to be used in policy analysis? We will return to issues of measurement at the end of the paper, but conceptual questions will be the principal focus.

While the conclusions which we will eventually draw have implications far beyond endangered species policy, a certain concreteness will be added if the reader will allow us to use an actual study to aid in the exposition. A study conducted by Boyle and Bishop (1987) estimated that preventing extinction of the striped shiner, a Wisconsin endangered species, would be worth about $12 million annually to Wisconsin taxpayers. Full details of the study are presented in the published paper and need not occupy us here. Their results will serve as an especially useful example because the striped shiner, a small minnow inhabiting the rather turbid depths of the Milwaukee River, has no known present or likely future uses. Assuming, for the sake of argument, that the $12 million is an accurate measure of the equivalent surplus of Wisconsin taxpayers for the striped shiner, it can be interpreted as a pure existence value.

A result like this raises at least five sets of conceptual issues, which we shall attempt to address here. First, what can be said about the "existence" of existence value? In this particular case, can people really place a positive value on existence of something which was unknown to them prior receiving the survey and which they never plan to use? The second set of issues will be termed the "project selection problem."[2] For example, suppose there is a project that would mean the difference between survival and extinction of the striped shiner. Would project costs of less than $12 million constitute a strong economic case for undertaking the project? The third set of issues will be here termed the "adding up problem". A common reaction to existence value is that if striped shiner values were added to other values that might be expressed by Wisconsin taxpayers, say those for grizzly bears, prevention of acid rain, preservation of wilderness, and other "environmental good things," then the sum would quickly become unbelievable. A fourth set of issues can be summarized by supposing that a chemical spill wipes out the shiners. Would we conclude that Wisconsin taxpayers have sustained "damages" of $12 million? This question boils down to a question of property rights. Fifth will be the problem of high per unit values. Suppose that there are 1,200 striped shiners left in the state. Then, they would be worth $10,000 each! How could any fish be worth that much?

The "bottom line" of this paper is that existence value creates no new conceptual problems for resource valuation. However certain problems that are well-known on a more general level take on added importance when existence values are interpreted in the context of public decision making. Let's see what is involved.

On the "Existence" of Existence Values

In his seminal paper, Krutilla (1967) suggested that wilderness might have a value to those who simply enjoy knowing that it exists. He drew a distinction between existence value and bequest value, the latter relating to the desire to leave natural amenities and other public goods to heirs and to future generations in general. The distinction between existence and bequest values persists in the literature to this day (e.g., Loomis, 1987), but here we shall use a more general definition of existence value, where the desire to leave things for future generations is one of several possible motivations for holding existence values.

We will use the term "resource existence values" to mean values for natural resources that are motivated from sources within the utility function other than those related to personal use of the resource by the individual consumer who is the focus of the analysis. For wildlife, following Boyle and Bishop (1987), three types of use are conceivable. Consumptive use involves some sort of extractive activities like hunting, sport or commercial fishing, and trapping. In the case of activities like commercial fishing and trapping, wildlife is a primary product in a vertical chain from resource exploitation to the final consumer. Demand for the in situ resource is a derived demand, but leads to a consumptive use value nonetheless. Sport hunting is an example of where consumptive use occurs in situ by the consumer whose value is being counted. Noncomsumptive use involves nonextractive activities that nevertheless involve in situ contact with the resource, such as bird watching, nature study, photography, and snorkeling. Indirect use involves reading about natural resources, watching television programs, and the like. Indirect use does not entail actual physical contact by the person in question, but does involve the purchase of some sort of market good to achieve the increase in utility. Other resources, such as wilderness areas, marine parks, plant resources, and wetlands would require that these definitions of use be adapted, but the principles would be the same.

If uncertainty is present, then possible future use in any of these categories could involve option values. This paper will quite intentionally avoid dealing at all with option values associated with future use. It will also leave to others any theoretical hair splitting about possible option values associated with future, but uncertain, existence values.

We now have a basis for defining existence values in terms of what they are not. They are the values derived from sources other than consumptive, nonconsumptive, or indirect use, now or in the future, by the consumer whose welfare is being evaluated. Nor do existence values relate directly to allowances for the risk preferences of that consumer. This is an attempt to capture at least part of what Krutilla and later writers were addressing, but it has a more formal, theoretical function as well. Boyle and Bishop (1987) pointed out that under this definition, any obvious basis for establishing weak complementarity between the existence of the resource and any market goods is ruled out. Some, such as Smith (1987), would include what we termed indirect use value as part of existence value. There is nothing inherently wrong with doing so, but it does muddy the theoretical water a bit in that it makes a part of existence value measurable, in principle at least, based on market data and a part of it not measurable. We prefer to make the break between existence and other values at a cleaner location.

Some economists have been skeptical of whether there can be value without some sort of use. One of the most skeptical has been Mendelsohn (1984), and it will be worthwhile to consider his own statement of his concerns.

> . . . there is reason to suspect that existence value may not even exist. After all, why would people value something with which they have no contact and for which they cannot anticipate contact. What difference would it make if it was not there? How would they even know it was not there when it ceased to exist? Clearly, if a lot of us possessed substantial existence value, it would give a shyster a lot of room to maneuver as he promised to preserve things but never did. Could we rightfully complain? Perhaps we could insist on third party verification that the creature remained. Would we pay a lot to hear a "yes," or would we want to know more. [Sic] Pehaps a film of the creature and an occasional book would do. But if this is all we want to know of the creature's existence, what would stop the shyster from making several such films and books and then destroying the creature. [Sic] It appears that most people's notion of existence value is probably another form of use value, and probably should not be added to direct and secondary use value.
>
> To test for existence value, it is necessary to eliminate potential use from consideration. For example, how much would you pay a millionaire who owned his own island to preserve some small fish in the middle of his property if it was clear that public access would never be granted to the area. [Sic] . . . Casual empirical evidence suggest that true existence value is zero. (Mendelsohn, 1984, p. 10)

Mendelsohn treats bequest value separately, pointing to a possible double-counting problem:

> . . . the present value of use is the discounted value of all future use of the resource. It is very difficult to tell in what way bequest value differs from the string of discounted future benefits of users. Bequest value appears to be future user value called by a different name. . . . If future use is properly incorporated into direct use measures, bequest value is redundant and should be ignored. (Mendelsohn, 1984, pp. 10-11)

Let us begin to address such concerns by first asking why people might place a value on maintaining a resource even if they would not personally benefit through consumptive, nonconsumptive, and/or indirect use. Altruism has played a key role in the conceptual literature on existence value (see, for example, Randall and Stoll, 1983), and rightly so in our opinion. In an earlier paper, Bishop and Heberlein (1984) suggested that existence value might stem from several kinds of motives. One is benevolence toward relatives and friends. Giving of gifts to friends and relatives is very common and would appear to stem partly from altruism. Why should such activities not extend to natural resources use opportunities? If Alpha would enjoy knowing that her neighbor, Beta, has the opportunity to watch birds in a certain marsh, both could benefit from marsh preservation. If Beta actually goes bird watching there, he receives a use benefit, but, contrary to what Mendelsohn seems to be saying, the value would not end there. Alpha would also benefit personally, and counting only Beta's use value would miss this existence value that accrues to Alpha.

Bishop and Heberlein also noted that existence value could be motivated by sympathy for and empathy with people and animals, by environmental linkages, by feelings of environmental responsibility, and by bequest goals. They pointed out (p.10),

> Even if one does not plan to personally enjoy a resource or do so vicariously through friends and relatives, he or she may still feel sympathy for people adversely affected by environmental deterioration and want to help them. Particularly for living creatures, sympathy may extend beyond humans.

Those who have watched the animal rights and anti-hunting movements cannot help but be impressed by the intensity of feeling that some people exhibit in that context, and potential future use values could hardly explain their motives. Environmental linkages relate to the "you've-got-to-stop-'em-somewhere" attitudes. Environmental concerns are widespread, and environmental events at Location A, which a given individual does not use, may cause her/him to feel more or less confident about events at Location B, which the individual does use. Motives based on feelings of environmental responsibility have to do with people's concerns about the effects of their consumption on environments that they do not personally plan to use. For example, if Gamma's consumption of electricity would otherwise contribute to acidification of Adirondack lakes, then she might be willing to pay something to have the generating plants where her power originates fitted with scrubbers so that she is not responsible for such harm. Bequest motives are a temporal extension of motives relating to benevolence toward relatives and other people into the temporal realm. Again, it seems that Mendelsohn and others miss the point. Yes, the beneficiaries may well receive use benefits and those use benefits are quite correctly counted. The point, however, is that the benefits do not end there. If the benefactor's utility function depends on the bequest, an additional value is created that is not counted if the beneficiary's use value alone is included in benefits.

Charitable giving and membership in organizations are often brought up in this context (e.g., Samples, 198?). Unfortunately, the evidence here is ambiguous. Dues to environmental organizations may result in use values through receipt of magazines or newsletters, access to facilities, and the like. Donations to general organizations do not provide an adequate basis for inferring specific resource values. Potential free rider problems prevent inferring much about magnitudes of values. Nevertheless, one suspects that making charitable donations and joining organizations does reflect existence motives to some degree.

To reject existence values would be equivalent to assuming that altruism in its various forms is totally lacking in the real world or does not apply to natural resources. Either assumption seems implausible based on seemingly altruistic acts that can be observed all around us every day. Existence value may be inconvenient for economics, but it cannot be ruled out a priori.

Returning to the striped shiners, then, there is no theoretical reason to doubt that they could really be worth $12 million to Wisconsinites. Why should respondents express positive willingness to pay for the shiner even though in all likelihood they had never heard of it prior to receiving the survey? The most plausible explanation, assuming that contingent valuation was working satisfactorily here, is that they were expressing a generalized demand for endangered species preservation. They were in effect saying, "What is this creature worth to me? I never heard of it before, but I am concerned about extinction, so given the opportunity posited in the contingent valuation question, yes, I would be willing contribute something for this particular one." Such values could be motivated by sympathy for animals, feelings of responsibility for the environment, bequest motives, and environmental linkages. Of course, specific motivations for existence values is an empirical question, and we propose this explanation of positive existence values for the shiner only as a working hypothesis.

However, reaffirming the theoretical plausibility of existence values only raises additional issues about how they should be interpreted in the policy arena.

<u>The Project Selection Problem</u>

At this point, we will introduce a formal model of existence value. Our model is not really different than those currently in the published literature, except that it will suit our purposes to have two resources in the model. Other theoretical modeling efforts, such as Randall and Stoll (1983), Boyle and Bishop (1987), Smith (1987), Madriaga and McConnell (1987), and Freeman (1989) have focused on defining the relationships between use and existence values and on specialized issues. Our model is a special case of earlier models in that we will assume that the existence of the resources being studied is all that matters to the theoretical consumer. A model focusing only on existence values will facilitate the exposition here and in the next section.

Suppose that the welfare of n consumers is affected by the existence of animal population of two different species, the striped shiner and the Higgins-eye pearly mussel, another endangered species in Wisconsin. Let us assume that there is no consumptive, nonconsumptive, or indirect use of either species, so that we can deal only with their existence values. To simplify the exposition we will take the extreme case where the consumer assumes that without the public sector intervention both species will become extinct in the near future. Suppose that the ith consumer has a utility function

$$U_i = U_i(X_1, X_2, Y_i),$$

where

X_1 = the population of striped shiners,

X_2 = the population of Higgins-eye pearly mussels, and

Y_i = the income of the ith consumer, a measure of consumption of market goods.

Letting U_{ij} = the first partial derivative of utility with respect to the jth argument, assume that

$U_{ij} > 0$, for $j = 1, 2$, and

$U_{iy} > 0$.

Let us also assume that

$$U_{i1}(0, X_2, Y_i) < \text{infinity}$$

and

$$U_{i2}(X_1, 0, Y_i) < \text{infinity},$$

so long as $Y_i > 0$. With regard to second derivatives, assume

$U_{i11} < 0$,

$U_{i22} < 0$,

$U_{iyy} < 0$,

$U_{i1y} > 0$, and

$U_{i2y} > 0$.

That is, marginal utility is diminishing for wildlife populations and income, and wildlife populations are complementary with consumption of other goods. Intuitively, this expresses the hypothesis that as people are able to acquire higher and higher levels of material well-being, they become increasingly interested in issues like extinction of endangered species.

One further derivative is of specific interest, the cross partial of utility with respect to mussels and shiners. If people who express existence values for such species are in fact expressing generalized demands for endangered species preservation, then one would suppose that obscure endangered species would be substitutable in the utility functions of Wisconsin taxpayers, and possibly highly substitutable. Respondents concerned about endangered species might not care much whether their money goes for shiners or mussels. Thus, we will hypothesize that the relationship between shiners and mussels is one of substitutability, i.e.,

$$U_{i12} < 0.$$

A theoretical definition of existence value is straightforward. Suppose that both the striped shiner and the mussel will become extinct in the absence of projects to save them. Further, suppose that a public project, called Project 1, would prevent extinction of the shiner but would have no effect on the mussel's survival. Using equivalent surplus as the welfare measure and symbolizing existence value of the shiner as EV_i^1, we have that

$$U_i(0, 0, Y_i) = U_i(X_1, 0, Y_i - EV_i^1),$$

where we take X_1 as the present population of shiners and we assume that the project does not prevent extinction of the mussel or affect consumption of market goods. A more general version where the project would only affect the number of shiners could be easily devised. Also, a comparable equation could be used to express EV_i^2, the existence value from a project that would prevent extinction of the mussel, but leave the plight of the shiner and market consumption unchanged.

Before we turn to the specifics of the project selection problem, a couple of related points regarding the theoretical modeling of existence value need to be noted. First, the convention of including the populations of animals in the the utility function and assuming positive, but diminishing, marginal utility as the population increases is receiving wide acceptance these days (for a recent overview, see Brown and Plummer (1989)).[3] As a theoretical abstraction, simply including the populations of shiners and mussels in the utility function is probably acceptable, but we suspect that a change in an animal population is likely to be viewed differently depending on the circumstances. For example, if 20 percent of the shiner population were lost because of some natural phenomenon like a severe winter, the loss of utility might be much smaller than if an equal number of fish were lost due to anthrogenic causes such as a chemical spill or vandalism. Second, although we have taken the extreme case of extinction as a point of departure for the model, the model itself would show losses of utility and hence effects on utility from less extreme events than total extinction. Our theoretical consumer would be willing to pay something to avoid loss of, say, 20 percent of the population.

While the model we are proposing here does not include a time element, it could be easily extended to do so. If we were to make the model intertemporal, we would not rule out the possibility that the consumer would have a positive existence value for avoiding temporary loss of some part of the population even if recovery were fairly rapid. Our discussion of possible motives for holding existence values implies that it would be a mistake to rule out, a priori, existence values for avoiding temporary losses of part of the population. Sympathy or empathy for animals, for example, could lead to such temporary existence values. We see no reason limit existence values to cases where natural resource losses are irreversible.

The model can be used to define and analyze the project selection problem in the following way. Suppose that the costs of a project to save the shiner are equal to C_1. Let the sum of EV_i^1 over all n consumers be EV^1 and suppose that $EV^1 > C_1$. How compelling would the economic case be for completing the project? This is the "project selection problem."

Why be concerned about project selection in this case? On one level, it must be recognized that having benefits greater than costs is never a terribly compelling case for project completion. A different design of the same sort of project or another project entirely might be better. In general, benefits in excess of costs only assures that the gainers from a project could compensate losers and still be better off; nothing can be concluded about the optimality of the project based on the sign of benefits minus costs. On this level, there is always a project selection problem whether existence values are thought to be an issue or not.

But, suppose that obscure endangered species are perfect or nearly perfect substitutes in the utility functions of our consumers. It would seem that project selection could become an especially relevant problem. Then, EV^1 reflects more of a generalized demand for endangered species preservation than a demand for striped shiner preservation per se. It would be even more incumbent on the analyst than usual to investigate cost-effective alternative means to save obscure endangered species rather than blindly accept the first project that happens to be evaluated. Given that, in the real world, there could be high substitutability not only among endangered species, but also between existence of endangered species and existence of other environmental "good things" (and possibly non-environmental "good things" as well), the economic case for any particular project based only on comparison of its existence values to its costs would seem to be weak.

If this whole argument turns out to be valid under empirical scrutiny, then there are two cases where the project selection problem would be less severe. First, uniqueness is obviously an overworked term in dealing with environmental preservation, but it seems likely that some environmental assets have fewer substitutes than others. Mussels are probably a much better substitute for striped shiners than for bald eagles, another Wisconsin endangered species.

Existence values for resources within major national parks and for well known animals like whales and bears can probably be used in applied welfare analyses with fewer concerns for project selection problems. Geographical proximity may also play a role. For example, the Adirondack Mountains may be viewed as having few substitutes by people in New York, but many substitutes by people in California. If so, perhaps New York residents' existence values for acid rain reductions in the Adirondacks should be taken as more compelling for policy than comparable existence values expressed by Californians. Another basis for differentiating between relatively unique environmental assets and general environmental good things might be based on underlying motives. One might view Adirondack lakes and wilderness in Alaska as very substitutable good things if other things are equal, but as very different products if one's electricity consumption affects the lakes, but there is no comparable link to Alaskan wilderness.

The second place where the project selection problem would seem to be muted is in the area of damage assessment from spills of toxics and oils, where the economist is asked to measure damages in monetary terms. Existence values do raise some other issues in this context discussed below, but project selection does not seem to be a problem. This is because the "project" has, in effect, already been selected. When the toxic substance or oil was spilled in a given location, the parameters of the thing to be evaluated were set. If welfare is affected in a way comparable to the welfare effects of extinction postulated above, existence value is determined, and is, from a welfare economics standpoint, as valid as any other welfare effect.

The "Adding Up" Problem

Closely related to the project selection problem is the problem mentioned at the outset as the adding up problem. Though to our knowledge no one has raised this question in the published literature, one commonly expressed concern is that there must be something wrong with existence value since there are hundreds of individual environmental good things that could be the subject of existence value studies. If we added up the existence values of each of them for any given member of society the sum would become implausibly large. To be a bit more precise, if the striped shiner is worth $4 to the average Wisconsin taxpayer (the average value per taxpayer used to calculate the $12 million figure for the state as a whole) and there are 100 obscure endangered species in Wisconsin, then would it follow that there is a value of $400 per taxpayer for obscure endangered species?

Let us suppose that, along with Project 1 as discussed above, there is a Project 2 that would save the mussel, but leave the shiner's situation and consumption of market goods unaffected. Suppose that if project 1 is completed, the population of striped shiners will be $X_1 > 0$, and that it will be zero otherwise. Likewise, if project 2 is completed, the mussel population will be $X_2 > 0$, and zero otherwise. Suppose that the costs of the two projects are C_1 and C_2, respectively. Define existence values as follows:

$$U_i(0, 0, Y_i) = U_i(X_1, 0, Y_i - EV_i^{10}),$$

$$U_i(0, 0, Y_i) = U_i(0, X_2, Y_i - EV_i^{02}),$$

and

$$U_i(0, 0, Y_i) = U_i(X_1, X_2, Y_i - EV_i^{12}).$$

Note first that if, as we have hypothesized, obscure endangered species are substitutes in the utility function, then adding up would involve a theoretical fallacy. Substitutability would mean that

$$EV_i^{10} + EV_i^{02} > EV_i^{12}$$

The left hand side of this expression could result from doing two contingent valuation surveys. In the first, respondents would be asked to value shiners assuming mussels will become extinct; in the second, they would be asked to value the mussels assuming that the shiner is extinct. The right hand side expresses their value in a survey where they are asked to value saving both the shiner and the mussel from extinction. Adding up, as on the left hand side, would indeed overestimate the combined value of shiners and mussels.

Note next that such adding up could lead to an aggregation problem. Letting EV^{10} be the sum of the EV_i^{10} over all n consumers and likewise for EV^{02} and EV^{12}, it is possible that

$$EV^{10} > C_1$$

and

$$EV^{02} > C_2,$$

yet

$$EV^{12} < C_1 + C_2.$$

The two projects, evaluated in isolation from each other, would pass the benefit-cost test, but a single project combining Projects 1 and 2, would not.

However, these are not problems peculiar to existence value. The potential pitfalls of ceterus paribus in welfare evaluation are well understood (Just, et al., 1982) and exist, not just for existence values or even for non-market values, but for all cases where commodities are related through complementarity or substitutability. Two implications follow in the current context. First, it would be incorrect to infer that if preservation of each of one hundred obscure endangered species is worth \$4 annually to a citizen, preserving all 100 species would be worth \$400. Theory would lead us to expect the value per species for 100 species to be less than \$4 and possibly a lot less if the substitution hypothesis is valid. Second, to the extent that existence values are subject to aggregation problems, this is a problem that exists across all kinds of values.

Unfortunately, however, this may not be the whole story. While simply adding up existence values is theoretically unjustified and existence values do not pose any new aggregation problems structurally, they may be qualitatively more troublesome than market goods in this regard. What worries us here is that there appears to be a large set of environmental good things that people view as important and that there is currently no way to express demand for these things except through very imperfect political processes. Both use and existence motives may be active. When such individuals are confronted with a contingent valuation question, this generalized interest and concern in broader environmental issues becomes focussed on the very specific environmental commodities that are the subject of the contingent valuation exercise. I do not mean to imply that the value is necessarily invalid. That is not the point. Rather, the result is that values could be very unstable and sensitive to the specific valuation context. The conditions covered under ceteris paribus could have a big impact on the values obtained. This would be one explanation for the results like those of Tolley et al. (1985) where existence values for air quality in the Grand Canyon for Chicago residents varied greatly depending on whether they valued air quality in Chicago first.

If this concern is valid, however, then there is still some comfort in recognizing that it is not a problem peculiar to existence values, but is the result of having a large bundle of things interrelated through substitutability (and possibly complementarity) that are important to people and that are largely outside the market system. Beyond that, this seems to be the project selection problem revisited. The value of any particular project is heavily dependent on the context in terms of other projects within which it is proposed. Simply having benefits greater than costs is not, in itself, a very compelling argument for any given project.

Thus, adding up is likely to remain something of a concern. Those who worry about adding striped shiners values to grizzly bear values to wilderness values may really be saying that we must think beyond individual projects, particularly those involving non-unique environmental assets, if we are to come up with cost-effective ways of satisfying generalized environmental demands. This does not make existence values wrong or irrelevant, but it does make them more difficult to interpret for policy.

The Property Rights Problem

Recall how this problem was illustrated in the introduction: If a toxic spill completely wiped out the striped shiner, making the species extinct in the state, should the taxpayers of the state be thought of as having sustained damages of $12 million per year?[4] One's first reaction is to say, yes. If, as has been postulated in this paper, striped shiners are an argument in the utility functions of taxpayers, then such a spill would cause them to suffer a welfare loss that we as economists are bound to recognize. Unfortunately, there is an issue here to which economists have given little attention. We are reminded of someone (Mishan?) asking whether putting arsenic in his rich aunt's tea should be considered an externality! The point is that society does not view all changes in utility as equally valid for consideration in making public policies. Some people may get disutility from adolescents with punk hairdos, but society may choose to ignore their loss in favor of allowing people the freedom to wear their hair as they please. In a similar way, society might choose to ignore people's concerns about the existence of some of the things they do not use.

This principle is particularly clear in a legal environment. Alpha may or may not be liable for a loss of utility inflicted on Beta depending on a whole host of factors. Some of these factors may be purely practical. For example, potential moral hazard on the part of those damaged may prevent an adequate assessment of the damages and help to rule out compensation. Alpha probably cannot collect damages if someone is struck down by an automobile in her presence no matter how traumatic the experience if the person run down is not related to her. Even for close relatives doing so has been difficult, although lawyers tell me that it is getting easier. I have not traced the legal history behind such restrictions, but suspect that moral hazard is probably one factor. In a broader sense and dealing with non-human impacts, there is probably a principle operating here that says that individuals cannot collect damages for harm done to something in which they hold no property rights.

Who actually owns what and what those property rights actually entail is much more the province of lawyers than economists, and whether existence values for harm to wildlife ought to count in court is for them to fight out. As interested observers, it seems to us that the commonly held notion that wildlife in the United States is the property of the people and held in trust by the state might be taken to mean that damages to existence values for wildlife ought to count. In this regard, it is interesting that federal and state governments are designated by CERCLA as "trustees." Also, as economists, we might try to say something about what sorts of property rights ought to exist. If indeed existence values are widespread and potentially large for society as a whole, we might suggest that, if there are large welfare effects that may not be fully recognized under the current property regime, then society should consider changing that regime to give those welfare effects greater recognition.

While property rights issues are most visible on the negative side where society tries to judge whose "ox is being gored" and by how much, the same set of issues arise in a more subtle form when one tries to evaluate the benefits of alternative steps that society could take in a positive direction. Bishop et al. (1990), for example, consider total valuation of Great Lakes ecosystem rehabilitation. The Great Lakes have suffered tremendous environmental insults over the years, and while I do not know of any empirical work, I would not be at all surprised if a study showed substantial existence values for restoration of those ecosystems. Such values, if they were counted in the policy debate over how to manage the lakes, would probably conflict somewhat with current sport and commercial fishing interests. The sport fishery, in particular, is based to a substantial extent on stocking exotic salmon and trout for a "put-grow-and-take" fishery. If existence values for restoration of natural ecosystems turned out to be large, this could point toward a major re-orientation of public programs in directions that would greatly reduce sport fishing benefits. Society may have to decide how much clout the values of non-users should have in decisions about how to try to manage the Great Lakes. I shudder to think about the potential political debate over whether to count existence values in the management of furbearers and sport hunting resources. Nevertheless, to ignore existence values in such areas is to invite the criticism that we economists are overly narrow (or, more bluntly, "biased") in choosing whose welfare to count in benefit-cost analysis and whose to ignore.

The High-Per-Unit-Value Problem

As an illustration here suppose that there are only 1,200 striped shiners left so that they are in effect worth $10,000 each. Is this cause for alarm or disbelief? Actually, the answer is rather straightforward to anyone with an economics background. Existence is a public good, which means that one fish can simultaneously satisfy demands of many people. The average of $10,000 per fish only seems preposterous because we are used to thinking of fish in their roles as private goods.

To some extent, I raised this question only because someone needs to address it in print. Having done that, however, it is worth noting that it is the public goods character of existence that makes it such a potentially important concept. Public goods deserve special attention because use of relatively small quantities of resources can produce large benefits by providing non-rival consumers in large numbers with increases in welfare. Also, public goods need special attention because of the well-known result that private, individual property and market exchange do not appear to be a very promising approach to management.

Measurability

Before drawing together the conclusion, the prospects for measuring existence values need to be addressed. Existence value would be a useful concept even if it can never be measured precisely enough to be useful for quantitative policy analysis. In economics, as in other branches of science, it is as important to know what is not being measured as to know what is being measured. However, the usefulness of the concept would be greatly enhanced if monetary measurement were possible. A certain despair about the possibilities for measurement are detectable in the literature. Madriaga and McConnell (1987, p.936), for example, point out that existence benefits, "are less susceptible to disproof than benefits from the direct use of the resource. The conclusion that every household in the United States would pay $1.00/year to attain swimmable water in the Chesapeake Bay yields not just a large number but a number which is hard to refute." Some would, at least in conversation, go so far as to question whether existence value can be considered a scientifically and/or legally useful concept since it is in some sense "irrefutable."

Empirical validation of existence value measures is admittedly a difficult area, but the problem is far from intractable. While the purpose of this paper is not to review empirical studies in detail, two recent laboratory experiments deserve brief mention. Kealy, et al. (1986) examined both contingent and actual willingness to pay of university students for reductions in damages from acid rain. The results probably contain some use values, but appear to contain an element of existence values as well. Boyce, et al. (1989) investigated the value of Norfolk pine trees using both contingent valuation and cash transactions. Existence values entered through threats to kill the trees. For example, some of the respondents on the willingness-to-pay side of the experiment were told that unsold trees would be killed. Results from both of these studies are moderately encouraging. While both indicated that contingent values exceeded cash values, they appear to support the hypothesis that existence values can be greater than zero. Obviously, two studies are not conclusive, particularly when use values and existence values cannot be fully unravelled, but these studies do point toward an avenue through which the validity of contingent existence values can be studied. More research of this kind is badly needed.

Beyond experiments where actual and contingent existence values can be compared, other lines of research may also yield insights. Continuing to appraise the validity of contingent valuation method for use values will clarify where it performs well, where it does not, and why. This will provide some basis for inferring whether it is likely working well for existence values as well. Another approach would be to attempt to systematically study peoples underlying preferences for clues about presence and strength of attitudes and (non-monetary) values that could lead to non-zero (monetary) existence values. Such studies would require economists to look to psychologists, sociologists and other social scientists, but the potential benefits of truly interdisciplinary work on valuation is already very evident, not only in the collaboration of Bishop and Heberlein, but also in the work of Mitchell and Carson and Schulze and McClelland. Such studies of non-monetary values and attitudes would not provide iron-clad evidence that contingent existence values are accurate, but do provide insights through establishing or rejecting the convergent validity of various approaches.

Conclusions

Existence values are potentially too important to be ignored. Good theoretical work is a necessary first step toward empirical estimation. Theory guides empirical work and directs how the results are to be interpreted. So far, theoretical enquiry has identified surprisingly few barriers to including existence values in our resource valuation tool kits. There would seem to be no basis for ruling out existence values on a priori grounds. Stated differently, it is theoretically plausible that existence values could "exist". Though large per unit values do take ones breath away at first, they seem quite consistent with the public goods nature of existence.

It does emerge that project selection problems, though always present, could be particularly acute here. Furthermore, it will be up to the broader mechanisms of society to determine when people have a property right in the existence of environmental and other assets so that their existence values (if any) are to be counted and when they do not have such property rights. This process should not be viewed as a static one. If preferences and concerns that express themselves as existence values are becoming more evident these days and more capable of quantification, and if the welfare effects associated with existence are indeed substantial, property rights may well evolve to give existence values greater clout in public decisions.

Based on the large potential values involved, I would conclude that further research on existence values deserves a very high priority. Despite all the intellectual heat that option value has generated, option value is an economic tempest in a tea pot compared to existence value. My guess is that were we as a society to start measuring existence values and taking them seriously in environmental management and resource damage assessment the result could be a major realignment of national priorities in the direction of environmental protection and rehabilitation. Theoretical research is needed to build consensus on definitions, on theoretical relationships between value categories, and on correct approaches to empirical estimation. Laboratory and hopefully field experiments are needed to learn more about the validity of contingent valuation in general and with respect to existence values in particular. Such experiments will require collaboration with behavioral scientist. Additional collaboration to assess the possible convergent validity of monetary measures of existence value and underlying attitudes and preference is also desirable. Finally, applied studies should continue to estimate existence values in real world situations and explore their implications for public decisions.

We resource economists may well be accused of intellectual imperialism as we seek to incorporate ever wider sets of phenomena under the umbrella of dollar valuation. Is nothing sacred? Must we express absolutely everything in the metric of unrighteous mammon?

However relevant this criticism may be, we find ourselves in a "damned-if-you-do, damned-if-you-don't" predicament. To ignore existence value would be to court the equally damning criticism of having made a thinly masked value judgment in favor of considering use values as the only true economic values. Having come this far, do we dare turn away from this new challenge?

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Notes

1. Respectively, Professor, Department of Agricultural Economics, University of Wisconsin--Madison and Senior Project Manager, HBRS, Inc., Madison, WI. Research supported by the College of Agricultural and Life Sciences, University of Wisconsin--Madison, HBRS, Inc., and the Wisconsin Sea Grant Institute.

2. The term project will be used in its broadest sense. We mean not only capital projects, but also changes in public policies and services provided by the public sector.

3. Existence could be a binary variable in the sense that a species either exists (i.e., is viable in the long run) or it does not exist, but this is not a necessary assumption.

4. Let us agree that here, for once, we will not quibble over whether compensation demanded should be used instead of willingness to pay, as reflected in the $12 million figure. The focus here is on a different set of issues.

WHAT CAN WE LEARN FROM 20 YEARS OF WORK WITH TCM AND CVM?

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While issues in estimating nonmarket values continue to cause concern, natural resource and environmental economists now have more reason to be optimistic than ever before. More progress toward improved measurement has been made in the past six years than in the previous quarter century since development of the contingent valuation and travel cost methods. The new challenge is to learn how to adjust past studies to estimate nonmarket values for future policy analysis. The process involves developing an understanding of the important variables that explain the observed difference in estimates. This paper illustrates how the results thus far could be adjusted to develop some tentative estimates of the recreation use value of Forest Service resources.

This paper follows standard procedures developed by meta-analysis, the growing science of reviewing research (Cooper; Light and Pillemer). The approach introduces precision into the analysis with respect to specific purpose of the literature review; the selection of the studies for review; the similarity of the units of analysis and subject matter across studies; the distribution of study values; and the relationship of study values to research design, characteristics of participants, quality of the sites and management programs.

This paper draws on earlier versions of the work presented at the 1988 Western Agricultural Economic Association Annual Meeting and in Walsh et al. The study was funded, in part, by Purchase Order No. 43-82FT-7-1253, Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Dept. of Agriculture, Fort Collins, and by the Colorado Agricultural Experiment Station, Western Regional Project W-133, Benefits and Costs in Resource Planning.

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The source of data is the literature on demand for outdoor recreation with nonmarket benefit estimates from 1968-88. The study represents an update and evaluation of a previous review by Sorg and Loomis. Their 93 benefit estimates in studies completed from 1968-82 are supplemented with 20 they missed plus 164 estimates in studies completed from 1983-88. The 287 estimates of net economic value per day reported by 120 outdoor recreation demand studies from 1968 to 1988 are adjusted for method as in Sorg and Loomis and are in third quarter 1987 dollars.

Table 1 illustrates the resulting summary statistics for the recreation use categories of the Forest Service. Mean value of the estimates is $34 per day, with a 95 percent confidence interval of $31 to $37 and a range of $4 to $220. The median is $27. These values are shown for each activity along with output of the agency. Average benefit of activities ranges from $12 to $72 per day with the highest values reported for hunting, fishing, nonmotorized boating, hiking and winter sports.

Table 1 does not reveal what is causing the extreme range in values, whether variation in characteristics of users, quality of sites, or research methods. A potentially useful approach to the data transfer problem would be to pool the data from existing studies and apply multiple regression analysis. If the basic model specification is complete, that is, if it includes the relevant explanatory variables in the correct functional form, then it could explain the variation in benefits.

<u>Research Procedure</u>

A systematic search of the available literature was conducted in an effort to review as many empirical studies as possible from 1968 to 1988. The

Table 1. Net Economic Values Per Day Reported by TCM and CVM Demand Studies from 1968 to 1988 Applied to National Forest Recreation Use Categories, United States (Third Quarter, 1987 Dollars)

Activity	Visitor days 1,000[a]	Number of Estimates	Mean	Median	Standard Error of the Mean	95% Confidence Interval	Range
Total	226,533 (100.0%)	287 (100.0%)	$33.95	$27.02	1.67	30.68– 37.22	3.91–219.65
Camping, Picnicking, and Swimming	66,811 (29.5)	36 (12.5)	20.14	17.80	1.80	16.61– 23.67	7.05– 46.69
Camping	53,666 (23.7)	18 (6.3)	19.50	18.92	2.03	15.52– 23.48	8.26– 34.89
Picnicking	7,838 (3.5)	7 (2.4)	17.33	12.82	5.08	7.37– 27.29	7.05– 46.69
Swimming	5,405 (2.3)	11 (3.8)	22.97	18.60	3.79	15.54– 30.40	7.05– 42.94
Mechanical Travel and Viewing	68,423 (30.2)	11 (3.8)	25.42	21.44	5.14	15.35– 35.49	8.27– 68.65
Sightseeing and Off-road Driving	62,451 (27.6)	6 (2.1)	20.29	19.72	3.73	12.98– 27.60	10.33– 31.84
Boating, Motorized	4,301 (1.5)	5 (1.7)	31.56	25.67	10.36	11.25– 51.87	8.27– 68.65
Hiking, Horseback Riding, and Water Travel	19,900 (8.8)	17 (5.9)	41.74	24.72	10.53	21.10– 62.38	10.26–183.36
Hiking	12,740 (5.6)	6 (2.1)	29.08	23.62	5.82	17.67– 40.49	15.71– 55.81
Boating, Nonmotorized	3,419 (1.5)	11 (3.8)	48.68	25.36	15.85	17.61– 79.75	10.26–183.36
Winter Sports	14,730 (6.5)	12 (4.2)	28.50	24.39	4.48	19.72– 37.28	11.27– 66.69
Resorts, Cabins, and Organized Camps[b]	15,117 (6.7)	2 (0.7)	12.48	—	—	—	3.91– 19.93
Hunting	15,276 (6.7)	83 (28.9)	41.69	34.88	2.72	36.36– 47.02	16.58–142.40
Big Game Hunting	10,729 (4.7)	56 (19.5)	45.47	37.87	3.47	38.67– 52.27	19.81–142.40
Small Game Hunting	4,015 (1.8)	10 (3.5)	30.82	27.48	3.51	23.94– 37.70	18.72– 52.04
Migratory Waterfowl Hunting	532 (0.2)	17 (5.9)	35.64	25.27	5.87	24.13– 47.15	16.58–102.88
Fishing	15,208 (6.7)	88 (30.7)	39.25	29.59	3.80	31.80– 46.70	8.13–219.65
Cold Water Fishing	10,687 (4.7)	39 (13.6)	30.62	28.49	3.24	24.27– 36.97	10.07–118.12
Anadromous Fishing[c]	— —	9 (3.1)	54.01	46.24	11.01	32.43– 75.59	16.85–127.26
Warm Water Fishing	4,072 (1.8)	23 (8.0)	23.55	22.50	2.46	18.73– 28.37	8.13– 59.42
Salt Water Fishing	226 (0.1)	17 (5.9)	72.49	53.35	14.05	44.95–100.03	18.69–219.65
Nonconsumptive Fish and Wildlife	1,532 (0.7)	14 (4.9)	22.20	20.49	2.30	17.69– 26.71	5.27– 38.06
Other Recreation Activities	9,537 (4.2)	9 (3.1)	18.82	16.06	3.65	11.67– 25.97	6.81– 43.39
Wilderness	12,014[d] (4.5)	15 (5.2)	24.58	19.26	6.10	12.62– 36.54	8.72–106.26

[a] Thousands of 12-hour recreation visitor days reported by the Forest Service, U.S. Department of Agriculture, for the year ending September 30, 1986. *Statistical Abstract of the United States, 1988*, p. 212.
[b] Resorts were 1.83% valued at $19.93 per day; seasonal and year-around cabins were 3.06% valued at $3.91 per day; and organized camps were 1.79% valued the same as camping.
[c] Anadromous fishing estimates included in cold water fishing. Estimated as roughly 5%.
[d] Included above.

selection process was designed to fairly represent all the research on the topic in the United States. Included were studies in journals, chapters in books, unpublished research reports, masters and doctoral theses, research reports from private organizations and government agencies, and conference papers. In a number of cases, the authors were contacted by phone to clarify a methodological question or to obtain the results of unpublished studies. The overall effect of the selection process was to provide sufficient studies to identify interesting trends and get a broad flavor of the findings from both published and unpublished studies.

The values reported here represent consumer surplus calculated by the authors of each study from the demand functions they reported. The net economic values are equivalent to the dollar amount participants would be willing to pay over and above their current expenditures to ensure continued availability of the opportunity to use recreation resources. The review is limited to studies measuring the onsite recreation use benefits provided by a natural resource of given quality. Many of the studies also estimate the change in benefits with changes in the quality of the resource and interested readers are referred to the detailed descriptions of the original studies for estimates (Walsh et al.). Also, the values reported here do not include the public benefits from preservation of resource quality such as option values of future use and existence values to the general population of users and nonusers (Walsh).

The standard unit of measurement is an activity day, defined as one person onsite for any part of a calendar day. When values are reported on any other basis than per activity day, they are adjusted to this common unit. For TCM demand functions, the appropriate unit of analysis often is number of trips, but most authors also report the results in terms of value per activity day.

If not, values per trip are divided by the reported number of days per trip. Similarly, annual values are divided by the reported days of participation. Household group values are divided by the number of persons and days of participation per person. Where the value of recreation activities are reported for hypothetical quality changes, the base value for current site quality is used. There is a problem of defining recreation activity days at some sites, notably reservoirs with camping, swimming, boating and fishing on the same trip. In this case, the concept of recreation use is based on the standard procedure of the U.S. Census in which an activity is defined as primary use when it represents over 50 percent of total individual activity while at the site.

Table 2 defines the explanatory variables included in the equations. Most are conventional measures and require little added explanation. Nearly all of the variables are qualitative, indicating that a particular treatment is either present or absent. Of primary interest are the three adjustments by Sorg and Loomis for omission of travel time, the use of individual observations, and instate sample coverage discussed earlier in this paper. Other important determinants of demand are included to hold constant their effects and to estimate the partial effect of each of these variables and other possible candidates for adjustment in benefit estimates. The other variables are: recreation activity; whether specialized or general; site administration; quality; location; inflationary adjustment; method; open-ended, iterative, or dichotomous choice question; zonal, household production or hedonic price approach. The variable list is constrained by the availability of information, time, and budget for this study. As a result, some potentially important variables are omitted: direct travel cost per mile, travel time cost per hour,

Table 2. Description of Variables in the Analysis

Name	Definition of Variable
Dependent Variable	Consumer surplus estimated by each study, standardized to average values per activity day, adjusted to third quarter 1987 dollars.
Site Quality	Qualitative Variable = 1 if site was rated by each study as uniquely high quality; 0 if medium or low.
Forest Service Administered	Qualitative Variable = 1 if the study sites were Forest Service administered; 0 if otherwise.
Mixed Public & Private Sites	Qualitative Variable = 1 if household survey of participants in an activity at public and private sites; 0 if otherwise (the omitted categories were other wholly public and wholly private).
Specialized Activity	Continuous variable = percent. Proportion of total recreation use of U.S. Forest Service resources in the activity category. Proxy of taste and preference for specialized vs. generalized activities.
Inflationary Adjustment	Qualitative Variable = 1 if data were collected for each study prior to 1980; 0 if 1980–1988.
Sample Coverage	Qualitative Variable = 1 if only in-state residents were included in the sample of users; 0 if out-of-state residents were also included.
Method	Qualitative Variable = 1 if CVM; 0 if TCM or other method.
Substitution	Qualitative Variable = 1 if a substitute price term was included in the TCM demand specification; 0 if otherwise.
Travel Time	Qualitative Variable = 1 if travel time cost was omitted in the TCM demand specification; 0 if time was included.
Individual Observation	Qualitative Variable = 1 if TCM sample units were individual observations; 0 if otherwise.
Household Production & Hedonic Price	Qualitative Variable = 1 if household production or hedonic price TCM procedure; 0 if otherwise (the omitted category was the zonal group approach).
Open-ended Question	Qualitative Variable = 1 if noniterative open-ended question was asked in a CVM; 0 if otherwise.
Dichotomous Choice Question	Qualitative Variable = 1 if dichotomous choice CVM question was used; 0 if otherwise (the omitted category was the iterative question).
Socioeconomic Characteristics	Proxy for socioeconomic characteristics of participants in the service area of the study site. The nine Forest Regions are qualitative variables. Alaska is the omitted region.
Recreation Activity	The 19 national recreation use categories are potential qualitative variables for activities. Omitted categories include activities with limited representation in the studies, i.e., resorts, cabins, and organized camps.

income and other specific socioeconomic variables, sample size, functional form, and type of estimator used.

A quality variable is included to control for specific characteristics of sites which vary among recreation activities and expectations of individual participants. Sufficient information is available in the studies to apply a rough index of site quality in three categories--uniquely low, ordinary and uniquely high--based on a review of the physical and biological information provided. A site administration variable is included to test the hypothesis that Forest Service administered site benefits are not significantly different from other public and private sites. A mixed public-private site variable tests the hypothesis that household surveys are more effective than onsite studies, whether public or private. A specialized activity variable tests the hypothesis that benefits are lower for general activities than for specialized activities. This may be interpreted as a proxy for taste and preference. The federal guidelines (Water Resources Council, 1983) differentiate between general recreation activities engaged in by a large number of persons and specialized recreation limited to fewer participants with unique preference patterns. The guidelines associate specialized recreation with higher unit-day values than general recreation.

An inflationary adjustment variable is intended to begin examining the question whether recreation values increase at the same rate as changes in the purchasing power of the dollar. For comparison purposes, the reported values must be adjusted for inflation. However, this is equivalent to assuming constant real prices, which would not be consistent with increased crowding and relative scarcity of natural resources available for resource-based recreation activities (President's Commission on Americans Outdoors). Moreover, the procedure assumes an equal proportional change in the reported values for any given year which tends to dampen (enlarge) the absolute dollar adjustment for studies reporting low (high) values. This is evident for surveys from 1968-79 when the inflation rate was 6.9 percent, compared to 4.8 percent from 1980-87. Finally, willingness to pay is, in part, a function of ability to pay which suggests that secular adjustments for per capita real income would be useful.

A method variable is included to test the hypothesis that intended willingness to pay estimates of the CVM are lower than behavior-based TCM. This would be consistent with the observation that TCM values the entire trip including the primary activity and secondary activities while the CVM usually values the primary activity alone. For example, TCM always values the entire time onsite per calendar day of a trip while CVM usually values only that part of the day that pertains to the primary activity, e.g., the 4 hours devoted to fishing each day.

Willingness to pay for a constant unit of recreation use of an existing site should be approximately the same since both methods yield similar though not identical demand curves. The TCM estimates an ordinary Marshallian demand curve while the CVM estimates a Hicksian compensating demand curve. Both approaches specify that benefit is a function of the number of trips to a recreation site, which is separable in consumption and subject to a budget constraint. If the specification of quantity and other variables can be controlled, theory suggests that there should be little or no difference between values obtained by the two methods.

A variable indicating location of the study sites in Forest Regions is included as a proxy for socioeconomic characteristics of the user population. Since the regression model controls for site quality and substitutes, the other important effect of location is the distribution of income and other socioeconomic characteristics of the population in the relevant market for the study site. While extensive data on household demographics and equipment ownership are available for outdoor recreation activities from national and state samples, similar information is available only for a small fraction of the studies reviewed here. Thus, this important feature of variation in benefits would have to be ignored without an effective proxy variable.

<u>Statistical Results</u>

With the increased output of empirical studies in recent years, there are enough data to begin understanding the variables that explain the observed differences in benefit estimates. Table 3 includes three functions showing the statistical relationship of recreation benefits to some important explanatory variables. These are for the total sample of 287 benefit estimates, 156 TCM and related estimates, and 129 CVM. The number of observations is sufficient for statistically significant analysis. The R^2, adjusted for degrees of freedom, indicates that 36 to 44 percent of the total variation in the reported values is explained by the variables included in the functions. The overall equations are significant at the 0.01 level. The t-statistics shown in parentheses beneath the coefficients indicate that about two-thirds of the variables (27 of 42) are significant at the 0.10 level or above. Omission of the coefficient for a variable (--) indicates that it is not statistically related to benefits.

The panel nature of the data render the usual statistical tests of the model an approximation rather than a precise estimate. Although the residuals are close to normally distributed, heteroscedasticity is likely to be present in any study with parameters drawn from different data sets. Even though review

Table 3. OLS Regressions of Recreational Values on Several Important Explanatory Variables, United States, 1987

Independent Variable	Description of Variable	Total Mean	Total Coefficient[a]	Travel Cost Method Mean	Travel Cost Method Coefficient[a]	Contingent Valuation Method Mean	Contingent Valuation Method Coefficient[a]
Site quality	1 = High 0 = Other	0.129	33.568* (7.51)	0.154	39.171* (6.06)	0.101	25.082* (4.42)
Specialized activity	Percent of Forest Service output	4.917	−0.574* (−2.23)	5.235	−0.679* (−1.83)	4.571	−0.147 (−0.519)
Forest Service administered	1 = Forest Service 0 = Other	0.230	4.931 (0.98)	0.218	6.204 (0.84)	0.248	2.594 (0.42)
Mixed public and private sites	1 = Mixed 0 = Other	0.596	9.891* (2.29)	0.571	6.933* (1.12)	0.636	13.539* (2.46)
Inflationary adjustment	1 = 1980–88 0 = 1965–79	0.564	−7.971 (−2.35)	0.436	−10.579* (−2.03)	0.721	−16.582* (−3.31)
Sample coverage	1 = In-state sample 0 = Other	0.115	−6.892 (−1.33)	0.186	−11.759* (−1.77)	0.031	−7.464 (−0.86)
Method	1 = CVM 0 = TCM	0.449	−8.098* (−2.34)		—		—
Sorg-Loomis adjustments	1 = Not adjusted 0 = Adjusted	0.578	−4.290 (−1.09)		—		—
Travel time cost	1 = Omitted 0 = Included		—	0.192	−13.333* (−1.90)		—
Substitution variable	1 = Included 0 = Omitted		—	0.647	−10.831* (−2.05)		—
Individual observation	1 = Indiv. obs. 0 = Other		—	0.333	17.950* (3.44)		—
Household production & hedonic price	1 = HP 0 = Other		—	0.083	9.499 (1.03)		—
Open-ended question	1 = Open-ended 0 = Other		—		—	0.333	−3.659* (−0.76)
Dichotomous choice question	1 = Dichotomous 0 = Other		—		—	0.101	3.503 (0.62)
Southern region	1 = Southern 0 = Other	0.094	−13.089* (−2.48)	0.122	−12.333* (−1.66)	0.062	−10.998* (−1.67)
Northwest region	1 = Northwest 0 = Other	0.052	−10.676 (−1.47)		—	0.039	−12.186* (−1.53)
Pacific SW Region	1 = Pacific SW 0 = Other	0.059	−10.683* (−1.66)		—		—
Intermountain region	1 = Intermountain 0 = Other	0.171	−9.252* (−2.18)		—	0.155	−13.517* (−2.98)
Salt water and anadromous fishing	1 = S-A Fishing 0 = Other	0.091	34.566* (6.20)	0.096	42.939* (5.10)	0.085	24.454* (4.02)
Big game hunting	1 = Big Game 0 = Other	0.199	21.817* (5.33)	0.186	23.037* (3.58)	0.209	16.664* (4.04)
Waterfowl hunting	1 = Waterfowl 0 = Other	0.063	11.325* (1.80)		—	0.093	7.042* (1.28)
Constant			33.579* (6.89)		33.769* (4.24)		28.543* (3.98)
Sample size			287		156		129
Adjusted R^2			.36		.39		.44

[a] *T*-ratios are shown in parentheses; a single asterisk indicates that the coefficient is significant at the 0.10 level or greater.

of the correlation matrixes indicates mostly low levels, multicolinearity is likely to result from inclusion of more than one benefit estimate from some studies. The t-statistics somewhat over-or under-estimate variable significance based on a Smith and Kaoru comparison of OLS estimates with the Newey and West variation of the White consistent covariance estimates of standard errors used in calculating t-statistics.

Of primary interest here are the variables estimating the effect of the three adjustments in benefit by Sorg and Loomis; namely, for omission of travel time cost, use of the individual observation approach, and for instate samples at sites with out-of-state users. The increase in reported values by 30 percent for omission of travel time cost seems to be about right. The statistically significant coefficient indicates that TCM benefits are about 34 percent less for the 30 studies omitting travel time cost, other variables in the equation held constant. (The 13.333 coefficient for travel time cost is 34 percent of TCM mean value of $39). On the other hand, the decrease in reported benefits by 15 percent for use of the individual observation approach seems quite conservative. The significant coefficient indicates that benefits are 46 percent greater for the 52 TCM studies using individual observations. The increase of both TCM and CVM values by 15 percent for omission of out-of-state users appears to be about right for the total sample where the coefficient shows a 20 percent increase, although not statistically significant. The 15 percent adjustment seems conservative for TCM studies where the significant coefficient indicates the correct adjustment would be an increase of about 30 percent. Thus, while the three adjustments appear about right or to err on the low side, their overall effect is reasonably correct. The regression for the total sample (Table 3) indicates that when variations in site quality, recreation activity, region, method, etc. are held constant, no significant difference remains between the mean value of adjusted and unadjusted studies.

Another critical issue, of course, in the evaluation of the Sorg and Loomis adjustments is whether they are supported by applied microeconomic theory, accepted econometric procedures and the federal guidelines. Obviously, some adjustment for the omission of travel time is required, however, the precise level is not known and would vary for each study site. The statistical effect of the travel time cost variable could be improved if specified as a continuous variable in dollars per hour rather than as a qualitative variable indicating presence or absence of the adjustment. With respect to the adjustment for use of individual observations in TCM studies, some economists argue that values from zonal studies should be increased rather than decreasing values from individual observation studies because of the dampening effect of aggregation problem in the zonal approach (McConnell and Bockstael). Finally, limitation of the sample to instate residents originates in the institutional constraints of the researcher. The precise level of adjustment for sample truncation would vary with the actual origin of the user population of each site.

The regression results indicate other prime candidates for adjustment not considered by the earlier work. Benefit estimates from TCM studies omitting an effective cross-price term for substitution could be decreased about 30 percent according to the regression results. If the behavior-based TCM becomes the accepted standard for benefit estimation, then the CVM estimates of intended willingness to pay would be increased by an average of 20-25 percent. The results suggest that benefit estimates from CVM studies using dichotomous choice questions may be closer to TCM benefit estimates, perhaps requiring about half as much adjustment. However, benefit estimates from CVM studies asking open-ended willingness to pay questions could be increased by 10-15 percent more based on the preliminary regression results considered here. These are but a few of the possible adjustments that should be considered in applying the Sorg and Loomis approach of making adjustments before presenting statistical summaries of the data in policy applications.

An important question raised by the Forest Service in applying the data to policy decisions is whether the benefit estimates from other public and private recreation sites are applicable to Forest Service resources. The insignificant coefficient for study sites administered by the agency suggest that there may be no appreciable difference. Apparently, the benefit estimates from the literature review apply to valuation of the agency's recreation program. In theory, benefit estimates for a forest lacking data can be predicted by inserting appropriate values of explanatory variables into the regressions. Unfortunately, an insufficient number of studies have been completed to obtain more than a few estimates of value by this method. The agency identifies 19 national recreation use categories in nine Forest Regions, or a total of 171. However, only three of the 19 national recreation use categories and four of the nine Forest Regions are significant in the models fitted to data from the study sites (Table 3). The other regions may not differ significantly from the average and thus cannot have significant coefficients, or possibly sample size for these regions is too small.

The specialized activity variable could provide a rough indication of the benefit for some activities with few studies. For example, the benefit of sightseeing and offroad driving, the largest single recreation activity with 27.6 percent of total output, would be $20 per day [= 39 - (27.6 x 0.679)] based on the TCM equation. This compares favorably to the mean of $20 for six studies of this activity (Table 1). Nonetheless, it seems likely that the agency will need to rely on a combination of several approaches until a greater number of studies of most recreation activities have been completed (McCollum et al.; Bergstrom and Cordell).

Finally, these results should be considered tentative and subject to revision with more complete specification of the model. Sensitivity analysis omitting various combinations of variables from the final equations significantly changes the coefficients of those remaining (as in Atkinson and Crocker; Smith and Kaoru). This suggests that leaving important variables out of the final equations may attribute too much of the variation in benefit estimates to the differences in method that are included. Nonetheless, the equations in Table 3 include many possibly important variables and provide a basis for eliminating some of them as serious candidates for new research. The task remains to discover how far these results can be generalized. The importance of continued research is illustrated by the conceptual and empirical difficulties associated with estimation and the potential importance of recreation benefit in the economic assessment of programs such as forest recreation.

Summary and Conclusion

This paper addressed the problem of information transfer, that is, the possibility of adjusting past studies to estimate benefits for long-run policy analysis. The process involves developing an understanding of the variables that explain the observed differences in benefit estimates. As a first step, the contribution of this paper was to update and evaluate a previous literature review that adjusted reported values before presenting summary statistics. The travel time adjustment was supported by the regression results while the adjustments for sample truncation and use of the individual observation approach were somewhat lower than suggested by those results. Overall, these three adjustments were reasonably effective. There was no significant difference between the mean value of adjusted and unadjusted studies. The regression results indicated other candidates for adjustment including substitution, CVM method, site quality, administration, recreation activity, and regional location.

The results should be considered tentative and subject to revision with further study. Much more research is needed to fully understand the problems of information transfer. The approach illustrated here appears to be sufficiently promising to indicate that it could be used to analyze other important problems. These include adjusting for variation in the treatment of monetary and time cost of travel, substitution, site quality, and the functional form used in TCM applications. CVM problems include adjusting for variations in the method of payment, functional form used to analyze dichotomous choice questions, and information on resource quality, uncertainty, and substitution possibilities. Newer methods of controlling for the effects of these and other sources of variation in the estimates give reason to believe that it may be possible to resolve many of the problems of nonmarket value research. It is particularly noteworthy that in both the TCM and CVM approaches, the link between consumer theory and statistical estimation may be improved via use of discrete choice and qualitative response models with maximum likelihood statistical techniques.

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OPTIMAL RISK PREVENTION AND EFFICIENT MULTIPLE USE OF PUBLIC LANDS

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I. INTRODUCTION

Amenity valuation under uncertainty has played a pivotal conceptual role in the economics of natural environments for over two decades. Since 1964 when Weisbrod first suggested that there was a premium above and beyond expected consumer surplus that uncertain demanders would be willing to pay, resource economists have been concerned that amenity benefits may be systematically underestimated by conventional estimation techniques. The possibility of not being able to get amenity benefit estimation "right" has far reaching implications, both for the efficient and the equitable allocation of rural land resources. As such, a great deal of analytic effort has gone into refining welfare theoretic measures of value for resources subject to demand or quality uncertainty.

The prescriptions resulting from recent research efforts have been diverse, conflicting, and at times controversial. It has been argued that option price is the appropriate second-best benefit estimate (Graham); that the contingent payment contract with highest expected value is required to fully reflect value (Cory and Saliba); that the choice of an appropriate measure of value depends in a complex way on the nature and existence of contingent-claims markets (Gallagher and Smith); and even that it is reasonable to expect little difference in these benefit estimates in applied work (Freeman 1984). While substantial refinement of valuation measures under uncertainty has taken place, concern remains that nonmarket techniques for benefit estimation, even when carefully and skillfully applied, may not be able to accurately reflect amenity values under uncertainty.

The purpose of this paper is to address these concerns in a new context using an alternative analytical framework. The context is one of multiple-use management of public lands. Uncertainty and amenity valuation are fundamental components in a comprehensive evaluation of efficient multiple use. For a wide cross-section of demanders, uncertain recreation quality is a principal determinate of willingness to pay. Here, the probability of enjoying a high-quality recreation experience directly impacts on an individual's valuation of amenity resources. Examples include hunters and the likelihood of a successful hunt, bird watchers and the chance to sight a rare bird, anglers attempting to catch the legal limit, and backpackers trying to enjoy an uncongested wilderness experience.

The alternative analytical framework is one of entitlements and protections, or what Bromley has recently described as a "general equilibrium" analysis of rights and privileges. The approach is to evaluate benefit measures within alternative entitlement or property-rights structures. Formulated in this way, the very definition of efficient multiple use becomes a function of entitlement and protection specifications and of the welfare theoretic measure of value such specifications imply.

In the following section, a valuation model is developed for evaluating efficient multiple use of public land when some uses generate certain benefits and other users generate benefits dependent on uncertain recreation quality. Section three expands the model and its implications for risk prevention, benefit measures, and efficiency to account for alternative entitlement structures. Welfare measures for amenity benefits under uncertainty are identified for combinations of property-rights and protection specifications. The paper concludes with a summary of findings, a discussion of the implications for contingent valuation procedures, and some suggestions for future research.

II. THE VALUATION MODEL

Assume public land is to be allocated to two competing uses. One use generates benefits which are dependent on uncertain recreation quality. The second use secures certain benefits while imposing external costs by adversely affecting recreation quality. Efficient use of land resources requires determining when the two uses should be treated as mutually exclusive, or if not, determining what combination of uses would maximize net benefits to the resource demanders. A familiar example of such a public land management issue is the conflict between elk hunting and cattle grazing in the West (Cory and Martin, Keith and Lyon). As cattle operations are allowed to expand, elk herds must be reduced to avoid exceeding the carrying capacity of the range. Increased ranching income must be traded-off against declining chances for a successful hunt. Other examples include providing more developed campsites for day campers which reduces the chance of sighting rare species for birdwatchers, or allowing more offroad vehicles which lowers the probability for backpackers to enjoy an uncongested wilderness experience. To determine how many cattle to graze, campsites to provide, or offroad vehicles to allow, a multiple-use model of public land allocation is required that accounts for how net benefits are impacted when the probability of enjoying a high-quality amenity experience is altered by competing uses.

Amenity Benefit Estimates For Supply Uncertainty

Consider an individual who is uncertain about the recreation quality associated with the use of public land resources (e.g., uncertainty about having a successful hunt, sighting a particular rare bird, or the size of a fish catch). How should the benefits generated by policies which insure continued availability of the resources be measured? For a given probability distribution across states of recreation quality, the measurement problem is one of determining the maximum expected value of contingency payments for which the uncertain user would voluntarily contract. Payments are contingent in the sense that an individual may be willing to pay different amounts depending on the quality of the recreation experience. For simplicity, assume that there are only two states of the world for the user within a given period: a state in which the quality of the recreation experience can be characterized as either high or low.1/ In this framework, benefit estimation would require identification of contingent-payment pairs for which the user facing quality uncertainty would contract to guarantee continued availability of a recreation area: a payment of C_H if the high-quality state should occur or a payment of C_L if the low-quality state materializes. Having identified these contingent-payment possibilities, the pair yielding the largest expected value is the appropriate measure of maximum willingness to pay.[2/]

Agreeing to a contingent-payment scheme is assumed to guarantee supply of resource services. If no such payment plan is contracted, the uncertain user forgoes these services and utility in the absence of the resources becomes $\bar{U}$, where

$$(1) \qquad \bar{U} = U(Y, P, X, 0),$$

and U is the indirect utility function without access to public land resources, Y is income, P is vector of relative prices, X is a vector of additional factors affecting utility, and 0 indicates unavailability of the recreation area. This utility outcome is illustrated in figure 1a by point g, where utility is portrayed as state dependent in such a way that the same income level provides a higher level of utility in the high-quality state (U_H) than in the low-quality state (U_L).[3/]

A rational individual would be unwilling to agree to any contingent-payment plan which would make him worse off (i.e., results in an expected utility level less than $\bar{U}$). One possible payment scheme that would not violate this condition involves expected surplus (E[S]). Letting S_H and S_L represent compensating surplus in the high- and low-quality states, respectively,

$$(2) \qquad E[S] = \eta_H \cdot S_H + \eta_L \cdot S_L,$$

where S_H is defined by $U_H(Y - S_H, P, X, 1) = U(Y, P, X, 0)$; S_L is defined by $U_L(Y - S_L, P, X, 1) = U(Y, P, X, 0)$; U_H and U_L are the utility functions in the high- and low-quality states, respectively; η_H and η_L are the probabilities of being in the high- and low-quality states, respectively; and 1 indicates that the land resources are available.

As illustrated in figure 1a by points a and b, agreeing to a contingent-payment contract of (S_H, S_L) will not make the uncertain user worse off in terms of expected utility, while insuring supply. Thus, this contingent contract is one measure of the individual's willingness to pay and is illustrated in figure 1b by point H, where S_H is paid in the high-quality state, S_L is paid in the low-quality state, and expected utility is $\bar{U}$.[4/]

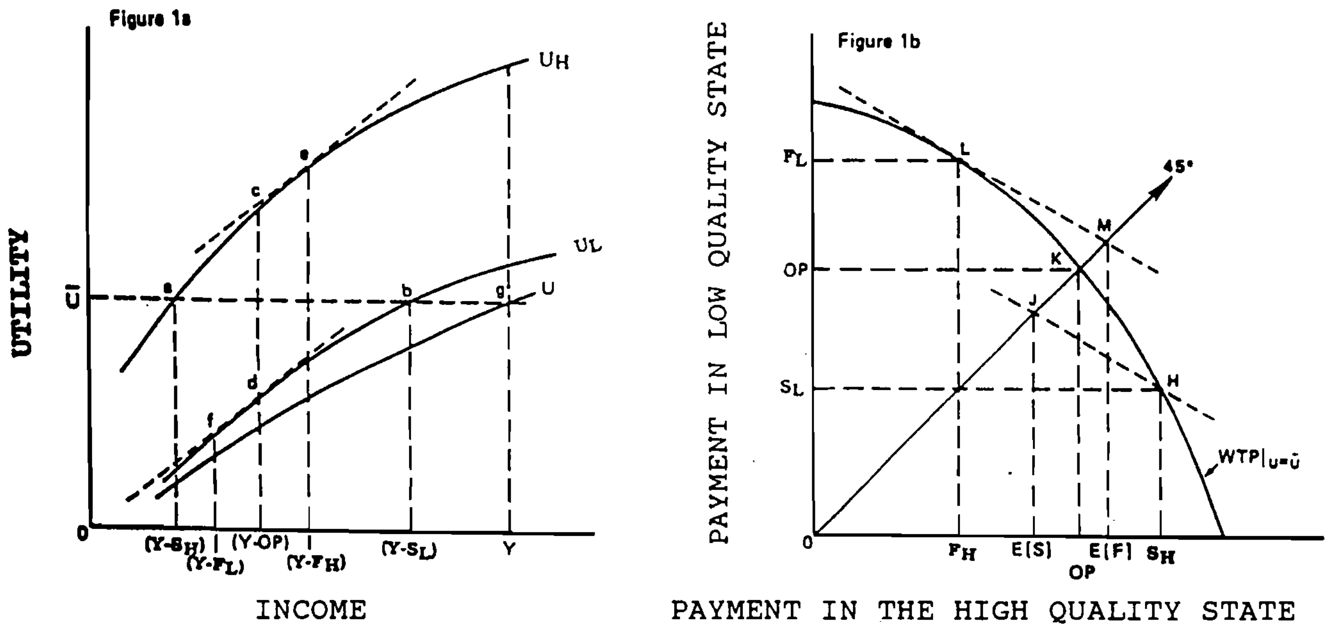


Figure 1. Uncertain recreation quality and alternative amenity benefit measures

A second possible benefit measure involves option price (OP). Option price is the maximum state-independent payment the individual would be willing to make to insure supply; that is, OP is defined by the following condition:

$$(3) \qquad \bar{U} = \eta_H \cdot U_H(Y - OP, P, X, 1) + \eta_L \cdot U_L(Y - OP, P, X, 1).$$

As with E[S], a contingent-payment contract of (OP, OP) will again insure supply without making the uncertain user worse off. This benefit measure is illustrated in figure 1a by points c and d, where, for graphical purposes, it is assumed that $\eta_H=\eta_L=.5$. Thus, OP is a second measure of an individual's WTP, where OP is paid regardless of which quality state is realized and expected utility is again $\bar{U}$ (point K in figure 1b). The difference between OP and E[S] is called option value (OV). Freeman (1984), Bishop (1982), Graham, Smith (1985), and others have examined conditions under which the size and sign of OV is determinate.

More generally, contingent-payment combinations that result in an expected utility level of $\bar{U}$ are given by the willingness-to-pay locus developed by Graham. This locus consists of all contingent-payment pairs (C_H, C_L) that satisfy the following:

$$(4) \qquad \bar{U} = \eta_H \cdot U_H(Y - C_H, P, X, 1) + \eta_L \cdot U_L(Y - C_L, P, X, 1).$$

The definition of this locus insures that expected utility when payments are made and the good is available is equal to expected utility when no payments are made and the good is unavailable, $\bar{U}$. That is, an individual is indifferent between making any of the pairs of contingent payments on the locus and being guaranteed access to the resource, and making no payments and being denied access to the resource.

Assuming the individual is risk averse (i.e., marginal utility of income is diminishing), it is straightforward to show that the willingness-to-pay locus is concave to the origin.[5] This locus is illustrated for one uncertain user of wildlife resources in figure 1b by WTP. Given the user's probabilities of being in the two states, the expected value of the first two benefit measures discussed [(S_H, S_L) and (OP, OP)] are illustrated by J and K, respectively.[6] In this case, option value (the difference between OP and E[S]) is positive. However, alternative specifications of the willingness-to-pay locus could yield positive, negative, or even zero option value.

Estimating maximum willingness to pay involves specifying the contingent-payment pair on WTP which has the maximum expected value. This combination is known as the fair-bet point and, in general, is distinct from both the surplus and option price combinations.[7] That is, neither E[S] nor OP correctly estimates maximum willingness to pay. A necessary condition for maximizing the expected value of contingent payments (i.e., maximizing E[C] $= \eta_H \cdot C_H + \eta_L \cdot C_L$ subject to (4)) is that the marginal utility of income be equated across states. This is illustrated in figure 1a by points e and f, where the marginal utilities in the high- and low-quality states are equal and expected utility is $\overline{U}$. The fair-bet payment in the high-quality state (F_H) and low-quality state (F_L) occur at point L on the WTP locus in figure 1b, where the slope of the individual's willingness-to-pay locus equals the ratio of the state probabilities.[8]

In empirical application, the appropriate measure of amenity value for the individual (i.e., E[S], OP, or E[F]) depends upon the aggregation rule and implied definition of Pareto improvement adopted (Smith (forthcoming); Cory, Colby, and Gum). Graham, Bishop (1986) and others have argued that aggregating OP is the correct procedure for benefit estimation when contingent claims markets do not exist. Cory and Saliba have suggested an alternative aggregation procedure based on E[F]. While aggregation issues are critically important to amenity benefit estimation under uncertainty, they are not addressed in the following sections. The focus is to determine how widely these benefit measures can be expected to diverge at the level of the individual regardless of the aggregation rule employed.

Amenity Benefit Estimates For Risk Prevention

Three measures of amenity benefits for a demander of a recreation area with uncertain quality have been discussed. For multiple use management, it is crucial to know how amenity benefits are impacted by competing uses. In many applications this amounts to a problem of determining optimal risk prevention.[9/] By reducing the level of conflicting activities, the probability of enjoying a high-quality recreation experience can be increased. Efficient multiple use then requires improving the probability distribution across quality states until additions to amenity benefits for uncertain users are exactly offset by reductions in benefits for certain users.

It is assumed that uncertain demanders are not subject to either risk perception or risk communication problems. That is, η_H, S_H, and S_L are known. Further, it is assumed that opportunities for self-protection or self-insurance do not exist. For $\eta_H = \eta_H^1$, the WTP curve for an uncertain resource demander is illustrated in figure 2 as WTP_1 along with the associated E[S], OP and E[F] measures of value. If management decisions are implemented to increase η_H, the WTP schedule rotates outward through the compensating surplus point (S). Decreasing the likelihood of a low-quality recreation state occurring results in no increase in the surplus enjoyed in the high-quality state but does increase the individual's WTP. As WTP_1 shifts to WTP_2 in response to increasing η_H^1 to $\eta_H^2 > \eta_H^1$, three potential benefit measures are identified: 1) the change in expected surplus (MS), 2) the change in option price (MP), and 3) the change in the expected value of the fair-bet point (MF). The MS measure of risk prevention benefits is given by $(\eta_H^2 - \eta_H^1)\ S_H + (\eta_L^2 - \eta_L^1)\ S_L$. The MP measure of risk prevention is the difference between OP_2 and OP_1 where $U = \eta_H^i \cdot U_H(Y-OP_i,P,X,1) + \eta_L^i \cdot U_2(Y-OP_i,P,X,1)$, i=1,2. The MF measure of benefits is given by $\eta_H^2 \cdot F_H^2 + \eta_L^2 \cdot F_L^2 - \eta_H^1 \cdot F_H^1 - \eta_L^1 \cdot F_L^1$ where the fair-bet payments maximize the expected value of contingent payments given η_H without making the individual worse off.

For the discrete change in η_H illustrated in figure 1, MS > MP > MF. Other relative magnitude outcomes are clearly possible. As η_H varies from 0 to 1, E[S] increases linearly from S_L to S_H, E[F] increases nonlinearly from S_L to S_H and is bounded by S_H (Cook and Graham), and OP increases from S_L to S_H while being bounded from above by E[F] and from below by E[S], if option value is positive. The rate of increase for E[F] and OP depends

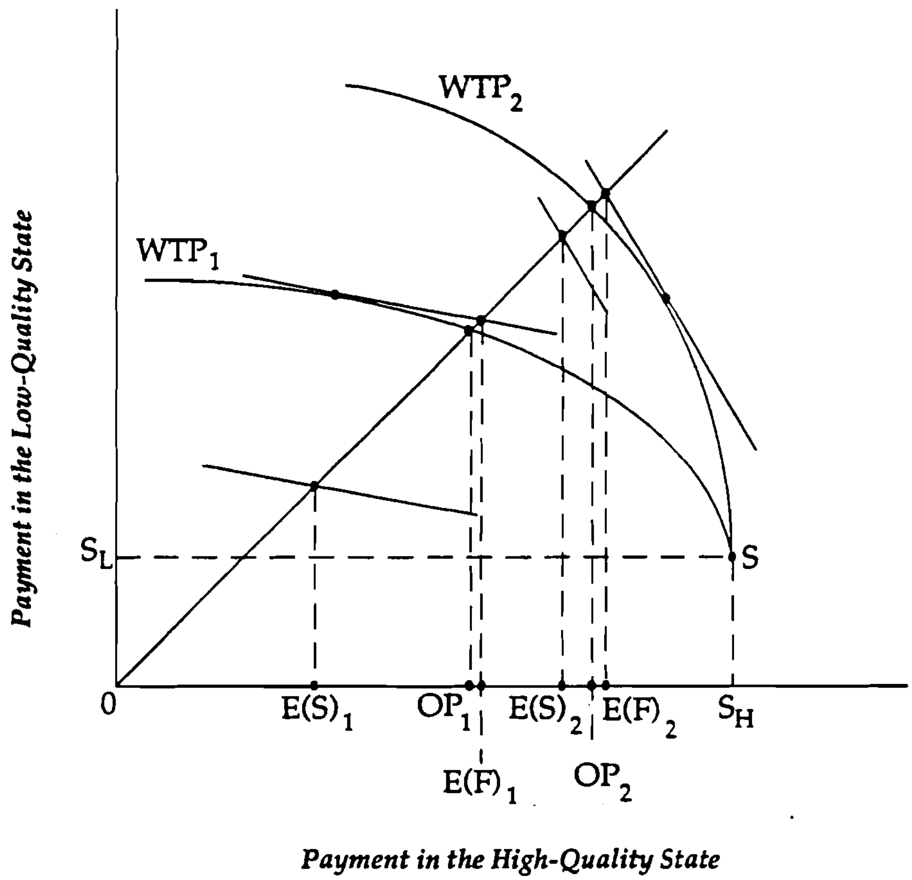


Figure 2. Amenity Valuation Under Uncertainty and Risk Prevention.

upon the nature of the state-dependent utility functions. For discussion purposes it is assumed that both E[F] and OP increase at a decreasing rate for increasing levels of risk prevention.

In figure 3a the behavior of total WTP as a function of risk prevention is illustrated for the E[S], OP and E[F] measures of amenity value, given previous assumptions. The corresponding marginal values are illustrated in figure 3b. Risk prevention measures can vary η_H between η_H^0, the high-quality probability associated with unrestricted levels of conflicting use, and η_H^1, the high-quality probability resulting from the total prohibition of conflicting uses. As η_H increases, the MF measure of benefits initially exceeds alternative measures, followed by a range of risk prevention in which MP is largest in magnitude, and finally a range in which MS bounds MF and MP from above. Lower bounds for amenity benefits attributable to risk prevention are initially provided by MS then MF.

For mutually exclusive uses of public land, the benefits accruing to users subject to uncertain recreation quality would be evaluated at $\eta_H = \eta_H^1$, the high-quality probability associated with prohibition of conflicting uses. In this case, amenity valuation issues concern the comparative merits of E[F], E[S] and OP measures of value and their relative magnitudes (points X, Y and Z in figure 3a). For multiple use of public land, increasing η_H generates benefits for uncertain users while imposing costs on certain users by restricting the level of their activities. In this case, amenity valuation issues must be concerned with the comparative merits of using MF, MS and MP measures of value,

Figure 3A

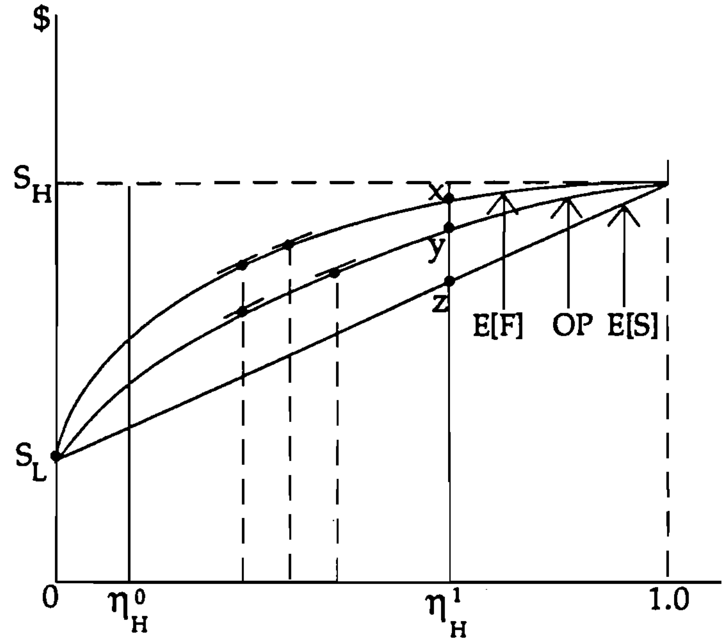
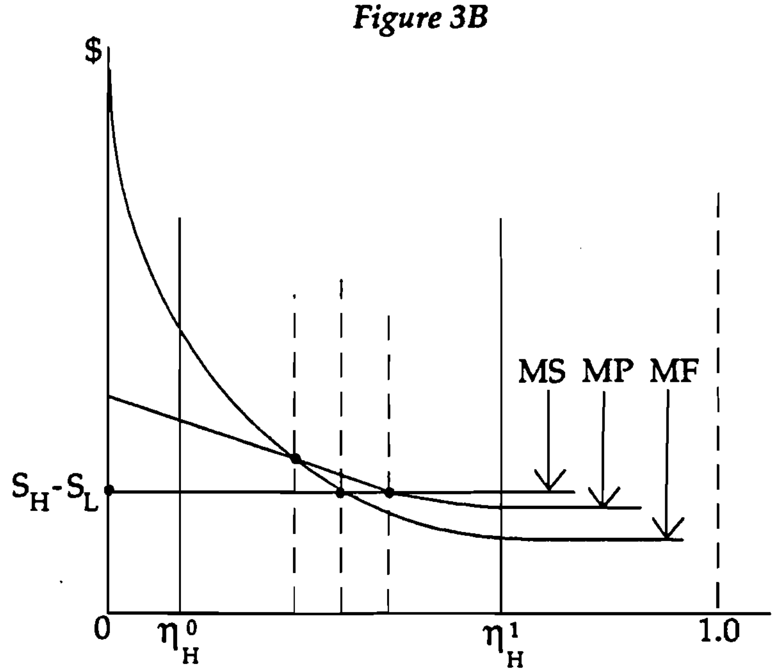


Figure 3B



Probability of High-Quality State Occurring.

Figure 3. Total and Marginal Willingness to Pay and Risk Prevention.

their relative magnitudes, the relevant range of risk prevention, and the associated costs incurred by conflicting users.

III. Alternative Measures of Risk Prevention Benefits: An Entitlements-Protection Assessment

Some insights into the comparative merits of MS, MP and MF in determining efficient multiple use can be gained by casting the issues in an entitlements-protection framework.[10/] Assume the uncertain amenity demanders comprise a group of identical individuals who can be represented by one member in the determination of multiple-use policy. Similarly, assume the certain demanders are identical and can be represented by one member. Resolution of this small numbers externality problem can then proceed in two steps. First, a determination must be made as to who is entitled to prevail. The certain demanders can be granted the right to engage in an unrestricted level of activity, or the uncertain amenity demanders can be granted the right to be free from harm. Having made a choice of entitlement, protection of the entitlement can then be afforded through liability or property rules. The applicability of MS, MP and MF measures of risk prevention benefits can now be evaluated for combinations of entitlement-protection specifications. It is assumed throughout that transaction costs are negligible. That is, strategic-behavior complications for property rules and imperfect-information complications for liability rules are not significant.[11/]

The probability of a high-quality recreation state occurring depends upon the level of conflicting-use activity (X). Specifically,

$$\eta_H = \begin{cases} \eta_H^{1}, & X \leq X_1 \\ \eta_H(X), & X > X_1 \end{cases}$$

where $\eta_H'(X) < 0$ and $\eta_H''(X) < 0$. Thus increasing η_H and amenity benefits for uncertain users requires decreasing the activity level for certain demanders and a subsequent reduction in their benefits. Three depictions of the costs incurred by certain demanders as η_H is increased are shown in figure 4 as MC_1, MC_2, and MC_3.

Now suppose an entitlement is granted to the certain users. Under either protection, net benefits are maximized by using the largest expression of WTP for the uncertain amenity demanders if collection costs are insignificant. For a property rule, increases in η_H beyond η_H^{0} would have to be negotiated based on the uncertain users WTP and the certain users willingness to accept (WTA). If the two groups are able and willing to negotiate to their mutual advantage, gains from trade are maximized by use of MF if $MC = MC_1$. The group of uncertain users is indifferent among outcomes along MS, MP and MF since they represent combinations of expected payment, distribution of risk, and η_H that result in $\bar{U}$. The certainty group would prefer to negotiate in terms of MF if collection problems are manageable since a portion of a+b+c can be captured depending upon negotiating skills. Similarly, if the entitlement is protected by a liability rule, net liability payments are maximized by

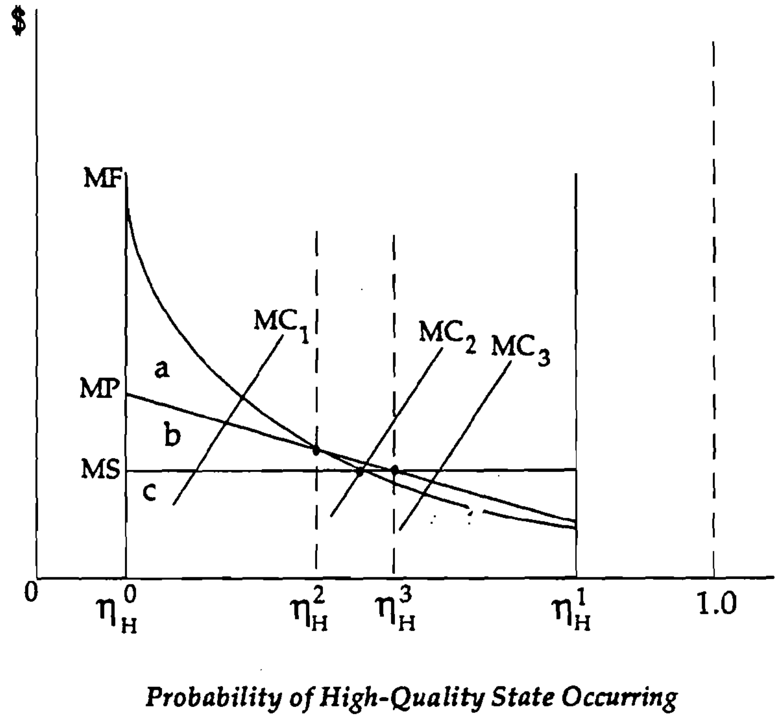


Figure 4. Risk Prevention, Entitlements, and Efficient Multiple Use.

setting marginal liability equal to MF when MC = MC_1. On average, the certainty group could be fully compensated, the uncertain group made no worse off, and net revenues of a+b+c would accrue to society if an MF liability rule is adopted. For both protections, an actual Pareto improvement is realized by using the MF measure of amenity benefits. If an intermediate entitlement of η_H^2 is granted, efficiency is again served by using the largest measure of WTP over the relevant range of risk prevention, in this case MP if MC = MC_2. With an intermediate entitlement of η_H^3 and MC = MC_3, MS becomes the appropriate measure of benefits in the absence of collection costs. Thus, no general case for one benefit measure can be made since the choice is dependent on specification of the entitlement, the efficient level of risk prevention, and the level of costs incurred by certain users.

Once collection costs are introduced, a stronger case for MP can be made. If there is individual risk and probability information is unreliable, or if states of nature are difficult to verify, then the certainty group might be hesitant to negotiate on the basis of MS or MF, and the process of collecting payments based on MS or MF liability rules could be considerably complicated. In graphical terms, with an entitlement of η_H^0 and MC = MC_1, the MF measure of benefits is preferred to MP only if collection costs are less than a.

The magnitude of collection costs could reasonably be expected to vary dramatically from one multiple use conflict to another. Information on the odds of a successful hunt might be more reliable than on probabilities of catching the legal limit. Similarly, catching the legal limit might be more easily verified than the enjoyment of an uncongested wilderness experience. While it is true that as collection costs rise, the comparative merit of MP is enhanced, no general case emerges for the universal application of either MS, MP or MF as an amenity benefit measure. If expected payment differences are large relative to collection costs, MS on MF may be preferred; if not, a case for MP exists.

A similar lack of resolution exists when an entitlement is granted to the uncertain amenity demanders. In this case, net benefits are maximized by using the smallest expression of WTA if compensation costs are insignificant. Under a property rule, reductions in η_H beyond η_H^1 would have to be based on the uncertain users WTA and the certain users WTP. By negotiating on the basis of minimum compensation gains from trade are maximized and can be divided between the two groups based on bargaining skills while leaving no one worse off. Under a minimum-compensation liability rule, the uncertain users would be fully compensated by the resulting mix of expected compensation, risk distribution and level of risk prevention while the net surplus to the certain users would be maximized. Once intermediate entitlements are introduced, either MS or MF benefit measures can be applicable depending on the specification of costs incurred by the certainty group and the efficient level of risk prevention.

Dropping the assumption of no compensation costs weakens the case for adopting MS or MF benefit measures. If probability information is unreliable or if states of nature are difficult to verify, then negotiation based on MS or MF becomes more problematic and the process of compensating the uncertainty group complicated.

Regardless of entitlement specification, a general argument for a particular benefit measure cannot be made. If the differences among MS, MP and MF are large over a given range of risk prevention relative to collection or compensation costs, MS or MF measures of benefits may be required to determine efficient multiple use. If not, use of MP becomes appropriate. In application, the choice may be a complex one crucially dependent upon entitlement and property rights specifications.

Conclusions

For mutually exclusive uses of public land, uses subject to quality uncertainty are evaluated on the basis of total WTP using either E[S], OP or E[F]. From a theoretical point of view, the choice among these measures can be a complex one depending on a variety of second-best considerations. However, Freeman (1984) has shown that there may be little at stake empirically when marginal utilities across states of nature are invariant for a given level of income. In this case, E[F] = OP and option value can be expected to be less than 10 percent. Contingent valuation could be considerably simplified if it could be further demonstrated that option value and option premium can be expected to be a small proportion of E[S] when marginal utilities are not invariant. Under these circumstances, a theoretical argument analogous to Willig's defense of consumer surplus could be posited for E[S]. That is, just as consumer surplus can be used unapologetically for assessing benefit impacts in organized markets, expected surplus could be used without apology to assess nonmarket benefit impacts in the context of mutually exclusive uses of public land.

For multiple use of public lands, uses subject to quality uncertainty are evaluated on the basis of marginal WTP using either MS, MP or MF. On theoretical grounds the choice among these measures is again a complex one depending not only on second-best aggregation considerations but also on entitlement and property rights specifications. Since the sign of option value and option premium are a priori indeterminate, information on their expected magnitudes would be particularly useful in applied work. Clearly more research on the benefits attributable to risk prevention will be essential in improving the efficiency of mutiple-use policy for public lands.

ENDNOTES

1. The theoretical results presented here could readily be generalized to a range of recreation quality states.

2. In this analytic framework, uncertainty is generated only by recreation quality since income is known and participation is certain.

3. For a more detailed discussion of this model see Cory, Colby, and Carpenter.

4. It is worth noting that an $E[\underline{S}]$ contract not only results in an expected utility level of $\bar{U}$ but also eliminates variability in utility outcomes. That is, regardless of which quality state materializes, utility will be $\bar{U}$. Throughout the discussion of benefit measures, it is assumed that the individual is a strict expected utility maximizer and is indifferent between contingent contracts of differing variability but identical levels of expected utility.

5. The slope of the willingness-to-pay locus is given by

$$dC_L/dC_H = -\frac{\eta_H \; \partial U_H/\partial Y}{\eta_L \; \partial U_L/\partial Y}$$

6. The expected value of a contingent-payment plan C is given by $E(C) = \eta_H \cdot C_H + \eta_L \cdot C_L$. Thus, a line through any contingent-payment combination with slope of $-\eta_H/\eta_L$ gives all combinations with the same expected value.

7. In figure 1a, it is assumed that marginal utility in the high-quality state (MU_H) is greater than marginal utility in the low-quality state (MU_L) over the relevant income range. If $MU_H = MU_L$ over this range, then the fair-bet and OP points coincide. This outcome was inferred by Freeman when it was assumed that indirect utility was strongly separable in income. However, Plummer later showed that such an assumption implies implausible conditions for the individual's direct utility function. In general, option price represents maximum willingness to pay, subject to the constraint that payments are identical in all states of the world. The fair-bet point, as an unconstrained measure of willingness to pay, has an expected value greater than or equal to option price.

8. These points are made in Graham's analysis for situations involving individual and collective risk. Individual risk in this context refers to state probabilities varying across potential users, a case that frequently applies to demanders of wildlife resources facing quality uncertainty. Collective risk requires that state probabilities be invariant across users.

9. This analysis is concerned with ex ante welfare optimality. For discussions pf ex ante and ex post welfare distinctions see Chavas et al., Hammon, and Ulph. Freeman (1989) has recently argued that ex ante measures of risk prevention benefits are desired in cost-benefit analysis and that little correlation between ex ante and ex post measures can be expected.

10. This Framework was originally suggested by Coase and has been extensively investigated by a variety of authors, most recently by Bromley.

11. For a discussion of the strengths and limitations of property and liability rules see Polinsky.

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USE VALUE UNDER UNCERTAINTY: IS THERE A "CORRECT" MEASURE?

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Use Value Under Uncertainty: Is There a "Correct" Measure?

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Last year, at these meetings and elsewhere, we developed a total value approach to benefit evaluation for the deterministic and uncertain cases (Randall 1989), Randall et al. 1989). In the deterministic case, the total value of a proposed change in environmental quality is the change in existence values plus the changes in all of the use values that derive from site experience and/or various activities. In keeping with the theory of BC analysis for complex policies (e.g., Hoehn and Randall 1989), valuation may be holistic or piecewise. A valid piecewise valuation structures must be sequence-dependent. Independent piecewise valuation structure are conceptually invalid. Empirically, they may under- or overstate the value of a policy with a small number of components; as the number of components grows large, the error becomes unambiguous and benefits are surely overstated.

The literature on BCA under uncertainty has grown quite huge and quarrelsome, as the concepts of option value and quasi-option value were introduced -- initially as adjustments that could be added to use values projected without reference to uncertainty (e.g., Weisbrod 1964, Krutilla 1967) -- and challenged and defended. Using the planned expenditure function (e.g., Smith 1987), we defined valid holistic and piecewise valuations for complex policies under uncertainty. It is notable that the valid piecewise structure includes existence and use values, but no new terms such as option value or existence value. The uncertainty is addressed -- rather than via new value categories -- by formulating total, existence, and use value in ex ante terms. These values are defined as the differences between *ex ante* (i.e., planned) expenditures.

This approach to total value under uncertainty -- which so closely parallels the deterministic case -- has a conceptual clarity and economy that is appealing. Further, it is capable of direct empirical implementation in contingent valuation studies designed, from scratch, to apply a valid holistic or sequenced piecewise valuation structure to the proposed environmental policy change.

Nevertheless, its pragmatic appeal is less than universal. Some practitioners would object to the need to always use empirical CVM studies custom-built from scratch. For example, the RPA values studies (Sorg and Loomis 1984) are designed to reduce research costs in applied BCA by documenting "typical" unit values for standard activities, to be used repeatedly in routine BC evaluations. Others would prefer valuation strategies that include a role for the travel cost method and hedonic price analysis, either because they prefer these methods which use *ex post* data from actual transactions or because they consider it sensible to at least use these methods occasionally as a check on CVM estimates.

However, the total value framework under uncertainty calls for *ex ante* values, whereas travel cost, hedonic, and "typical" unit values are usually considered *ex post*. Many would argue that a pragmatic strategy for routine BCA under uncertainty seems to require procedures for translating between *ex ante* and *ex post* values. Given the venerable identity,

(1) option price (OP) = expected surplus (ES) + option value (OV),

where OP is clearly an _ex ante_ value measure and ES is usually considered an _ex ante_ expectation of _ex post_ surpluses, the option value issue reasserts itself.

By "the option value issue," we mean the constellation of concerns that led originally to the proposal of option value in the 1960s. Is ES -- i.e., the mathematical expectation of _ex post_ consumers' surpluses projected into the future -- an acceptable measure of future uncertain use benefits? If ES is not, what is? If an acceptable measure of future uncertain use benefits can be defined, but ES can be measured readily, is there some measurable adjustment factor (OV, or some improvement thereupon) that can be used along with ES to calculate use benefits? Is ES, or OP, or any other readily defined measure of uncertain use value a reliable floor for uncertain use value?

In last year's paper (Randall, _et al_ 1989), we noted the Smith (1987) argument that _ex ante_ and _ex post_ value measures were conceptually noncomparable, to the extent that the logical coherence of the identity (1) is in doubt. If (a) the identity (1) is meaningless, (b) _ex ante_ benefit measures are essential for _ex ante_ BCA, and (c) travel cost, hedonic, and "typical" unit values are _ex post_ benefit measures, it follows that pragmatic BCA must depend on custom-built CVM applications in an _ex ante_ framework. We suggested that, in two specific situations, there may be a way out of this difficulty. First, not all actual transactions are made _ex post_ (i.e., after all of the uncertainty has been resolved). Advance purchase is a common arrangement (our example concerned airplane travel for vacations) and, in the absence of refunds, the purchaser bears uncertainty as to whether the trip will eventuate, what the weather will be like at the vacation site, etc. Sales of plane tickets under these circumstances might be interpreted as revealing *ex ante* willingness to pay. Second, there is often opportunity for the provider to relieve the demander of uncertainty (our example concerned an outdoor concert that the demander would not want to attend in the event of rain). The provider may undertake the full burden of this uncertainty simply by selling all tickets immediately before the event. If the provider can purchase fair insurance against rain (or is willing to self-insure), he will provide the concert if ES exceeds his *ex ante* expectation of the costs of provision. In this case, ES provides a floor on benefits, even though the import of the literature is that OP (a fairly standard measure of *ex ante* benefits) is likely to be less than ES.

Our purpose today is to extend and generalize these ideas and, in so doing, to simplify "the option value issue." In keeping with our goal of simplification, we will use diagrams almost exclusively and support our conclusions with intuitive arguments rather than formal proofs.

Policy in an Uncertain Environment

Assume an individual with preferences $u(y,p)$, where y is income and p is a vector of prices. If two states of the world are possible, the individual faces the outcomes $u(y_1,p_1)$ with probability π_1, and $u(y_2,p_2)$ with probability $\pi_2 = 1-\pi_1$. Thus, in some baseline or pre-policy situation, her expected utility,

$$(2) \quad EU^o = \pi_1^o u(y_1^o,p_1^o) + \pi_2^o\, u(y_2^o,p_2^o).$$

One could imagine policies to change any or all of π_1^o and π_2^o, y_1^o and y_2^o, and p_1^o and p_2^o. Uncertainty may pertain to incomes and/or prices, and policy may change incomes, prices and/or the probabilities associated with the preferred and less-preferred states.

As an aside, much has been made in the literature about the distinction between demand and supply uncertainty. However, it all boils down to this: if a demander of commodity z_1 is uncertain about its own price p_1, we are dealing with supply uncertainty; if the demander is uncertain about anything else in the utility function -- in our formulation, other prices or income -- we are dealing with demand uncertainty.

The Willingness to Pay Locus

Graham (1981) defined the WTP locus as consisting of ordered pairs (γ_1, γ_2) satisfying

$$(3) \quad \pi_1 \, u(y_1^1 - \gamma_1, p_1^1) + \pi_2 \, u(y_2^1 - \gamma_2, p_2^1) = \pi_1 \, u(y_1^o, p_1^o) + \pi_2 \, u(y_2^o, p_2^o) = EU^o.$$

This definition permits changes in prices and incomes, and is broad enough to encompass demand and supply uncertainty. However, it does not permit policy-induced changes in probabilities. We suspect this is not unduly limiting. First, one could readily define WTP when policy changes the probabilities, although it may be difficult to express it in the kind of two-dimensional diagrams that Graham and we prefer to use. Second, changes in the probabilities are merely an unnecessary complication if, as Hirschleifer (1970, p.217) claims, states can always be defined to guarantee that their probabilities are independent from human action. Graham seems to have done just that in his irrigation project example. Whereas some would conceptualize such a project as changing the probability of a farmer experiencing a poor season, Graham leaves the weather-related probabilities unchanged and treats the project as enhancing income if rainfall is low.

By (3), the WTP locus is a kind of _ex ante_ expected indifference curve. If the individual paid any pair of state-conditional payments on the WTP locus, she would be indifferent as to whether the proposal was implemented or not. If payments inside the locus were extracted, the individual would enjoy an _ex ante_ surplus from implementation. The individual would refuse to volunteer payments beyond the locus, since doing so would leave her _ex ante_ worse-off than without the project.

Any point (γ_1,γ_2) on the WTP locus can be interpreted as representing an _ex ante_ contract to make _ex post_ payments γ_1 if state 1 occurs and γ_2 if state 2 occurs. Three particular points, S, OP, and F (figure 1) have received special attention. S is an _ex ante_ contract to make _ex post_ payments S_1 in state 1 and S_2 in state 2, where S_i is the consumer's surplus from the policy in state i. OP is an _ex ante_ contract to make an _ex post_ payment of OP regardless of which state occurs. F is an _ex ante_ contract to make that pair of _ex post_ payments that has the largest _ex ante_ expected value.

Assume the project is provided by some entity (an entrepreneur or a public agency) that can extract consumers' surpluses and must collect revenue to cover its costs. The provider can always announce in advance the payment pair (S_1, S_2), and collect all payments _ex post_ (e.g., by selling all tickets at the time of use). This procedure will generate revenue of S_i in state i. Alternatively, the provider can sell all tickets in advance, i.e., _ex ante_, and collect OP regardless of which state occurs. To collect F, or any (γ_1,γ_2) combination other than S or OP, it must collect some combination of _ex ante_ sure payments and _ex post_ state-conditional payments; an obvious procedure is

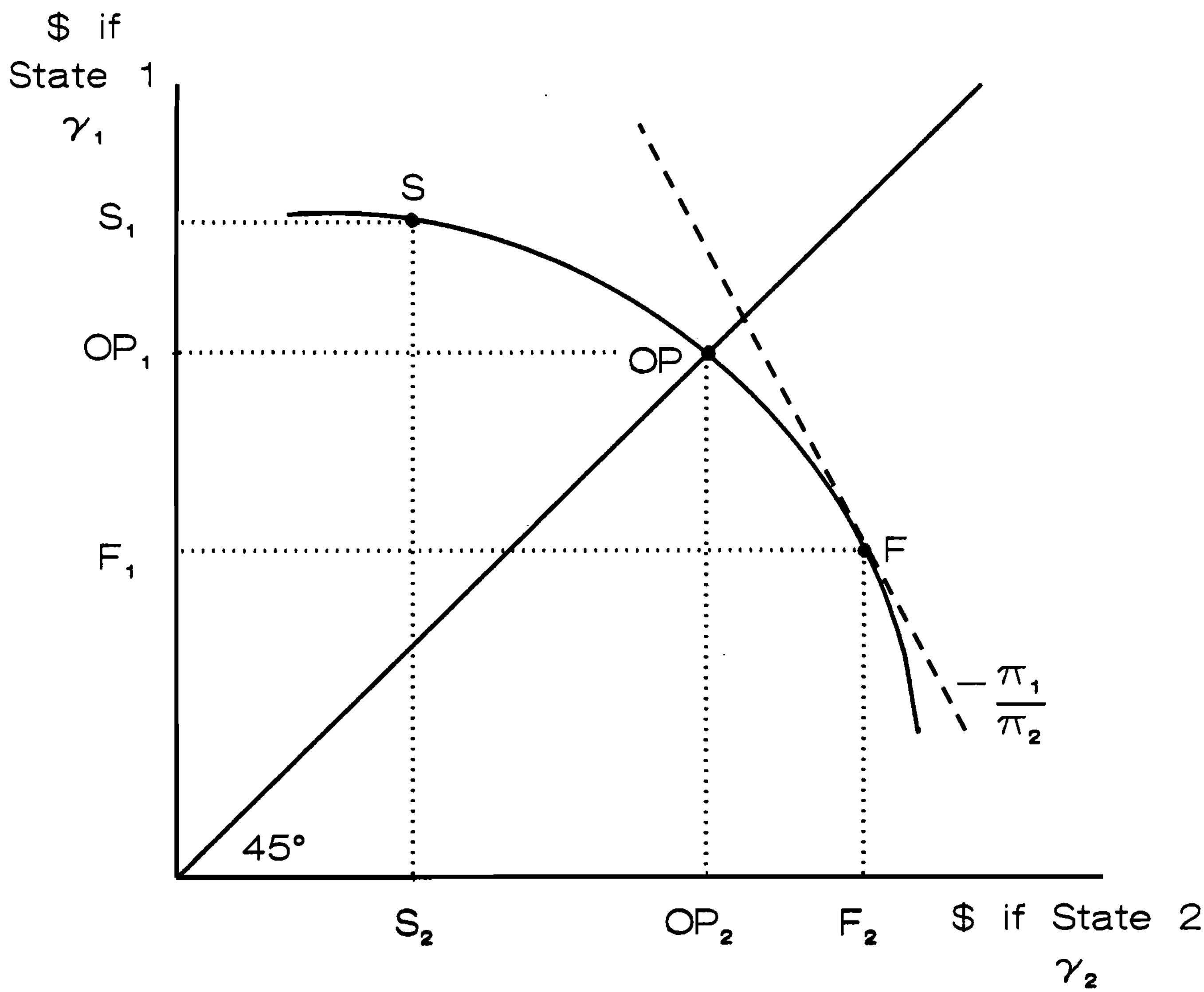

Figure 1. The WTP locus, S, OP and F

to sell tickets in advance and provide refunds ex post. F is simply that combination of advance payments and refunds on the WTP locus that generates the greatest expected value. The provider can collect any point on the WTP locus by permitting the demander to contract for the appropriate pair of state-conditional ex post payments.

The logistics of specifying a complete array of state-conditional payments (e.g., advance payments and ex post refunds) do not seem especially difficult to us. Nevertheless, if there are impediments to offering state-conditional payments, the provider will always be willing to provide the project if OP exceeds the cost. It is always possible to collect OP ex ante. Harking back to the total value framework (Randall 1989, Randall et al 1989) and to Smith (1987), OP is exactly ex ante use value in the case where ex post payments must be equal in either state and therefore equal to the ex ante payment. It follows that:

- **Use value under uncertainty is always at least as great as OP.**

Since OP has this property and is readily measurable and collectable, it is of considerably more merit as a benefit measure than Cory and Saliba (1987) suggest. OP supporters (e.g., Bishop 1986 and Ready 1988) have a point.

Stochastic Costs

It is reasonable to assume that costs are also influenced by the state of nature. Thus we can define a cost locus analogous to WTP. A cost locus consists of state-conditonal payment pairs that generate equal disutility. One obvious example is the case where costs are identical to the WTA of the prospective losers; this example highlights the analogous relationship between the WTP and cost loci. More generally, a cost locus is appropriate whenever costs are state-conditional. Disutility increases as one moves to higher cost curves. Uncertain use benefits are greatest when they will support the highest level of costs. As figure 2 is drawn, ex ante use benefits are maximized at the point WTP where the WTP locus and C_{WTP} are tangent. OP will support costs of C_{OP}, which exceeds C_S and C_F.

• **Without insurance, but with state-conditional pricing and stochastic costs, WTP is the valid measure of ex ante use benefits. The fair bet point, F, has no special merit as a benefit measure.**

With stochastic costs, we would interpret Ready's (1988) strong test for a potential Pareto-improvement to be that the intersection between the WTP locus and the cost locus be non-empty.

Fair Insurance and Certain Costs

Now, assume fair insurance is available. It may be provided by markets, by self-insurance, or by self-protection (Ehrlich and Becker 1972), assuming in each case that transactions costs are zero. Insurance against uncertainty that impinges on the demander may be purchased by the demander or the provider of the project. The provider could sell all tickets at the time of use at a pre-announced price -- thus relieving the demander of uncertainty -- and protect his revenue by insurance. Since transactions costs may be lower for a provider than for many demanders, (almost) fair insurance may be more readily available to providers. A provider who followed a strategy of S pricing and insurance would provide the project if it cost no more than ES for certain (figure 3).

• **With fair insurance (obtained by either the demander or the project provider) use value under uncertainty is always at least as great as ES.**

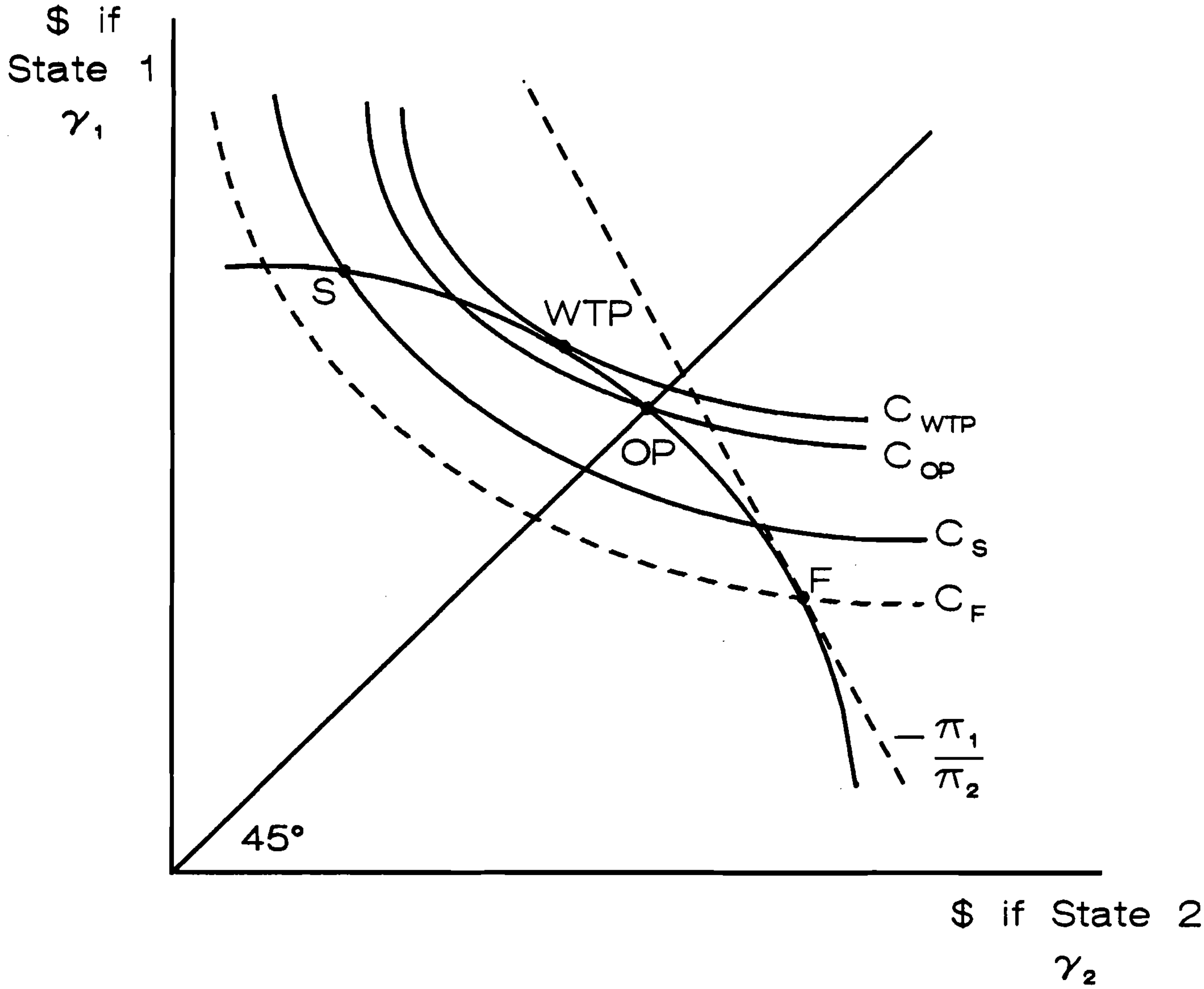

Figure 2. Uncertain Use Benefits and Stochastic Costs

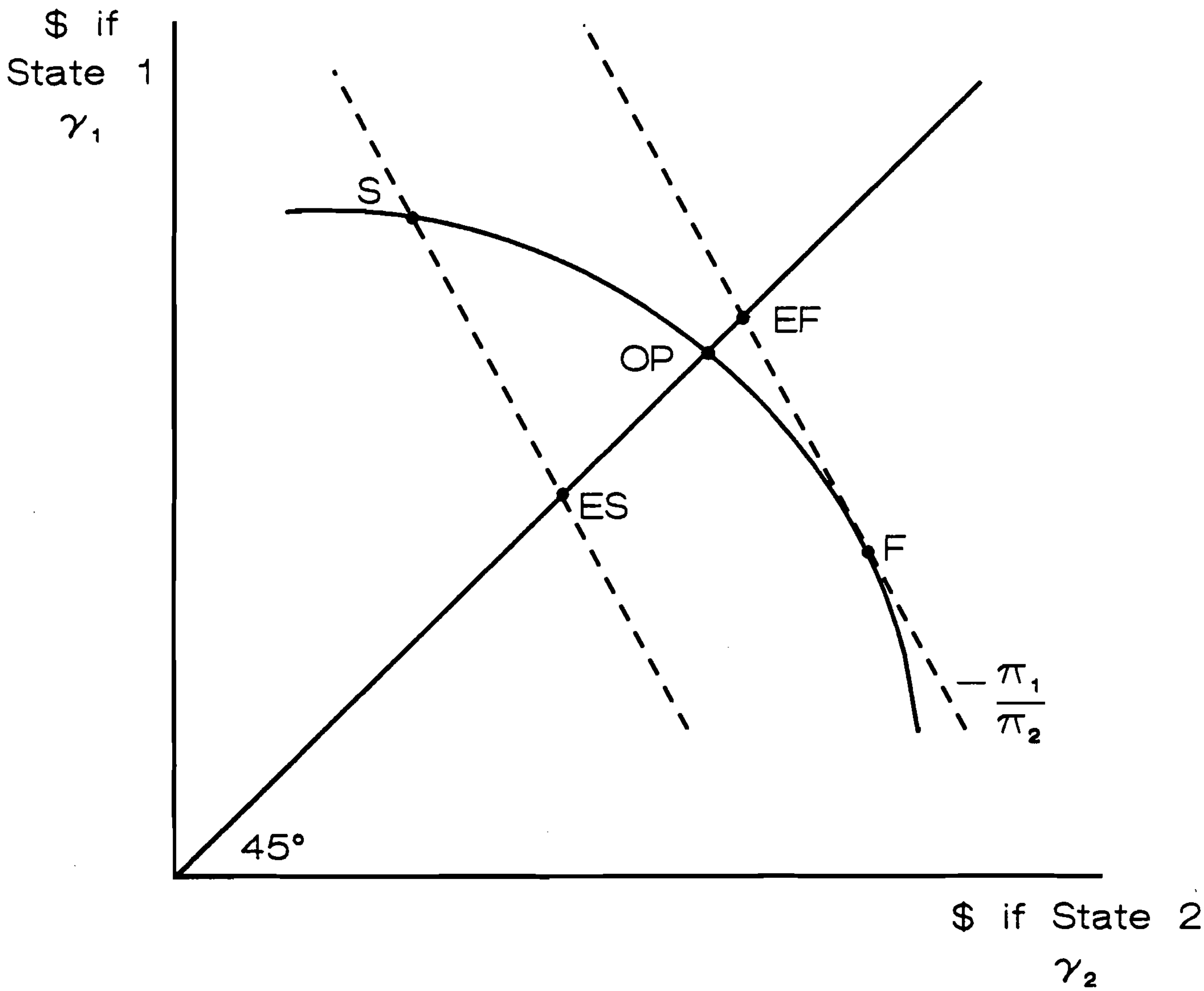

Figure 3. Fair Insurance and Certain Costs

Since it is always possible, alternatively, to extract OP under these conditions, *ex ante* use benefits are always at least as great as the greater of OP and ES.

With fair insurance and a complete array of state-conditional prices, a project would be provided at certain costs up to EF. The provider would collect state-conditional payments F and insure to guarantee revenue EF (figure 3).

- **While F has no special merit as a benefit measure, EF is a valid benefit measure for the specific case where there is a complete array of state-conditional payment possibilities, fair insurance and certain costs.**

In this connection, it is interesting to note that while Graham's (1981) figure 1 does not specifically identify EF, the point C identified (his figure 3) as "the maximum sure payment" is exactly ΣEF_j across all J beneficiaries. *Of course*, this provides an efficient allocation of risk among the beneficiaries.

Fair Insurance and Stochastic Costs

When costs are stochastic and fair insurance is available, both costs and benefits can be insured. Thus the insurance price lines passing through points S and ES, OP, and F and EF, respectively, become relevant (figure 4). Projects costing as much as the cost loci just tangent to these lines become supportable. Note that the supportable cost at S^* (figure 4) is at least as great as at S or ES; at OP^* is at least as great as at OP; and at F^* is at least as great as at F and EF.

- **With fair insurance and stochastic costs:**

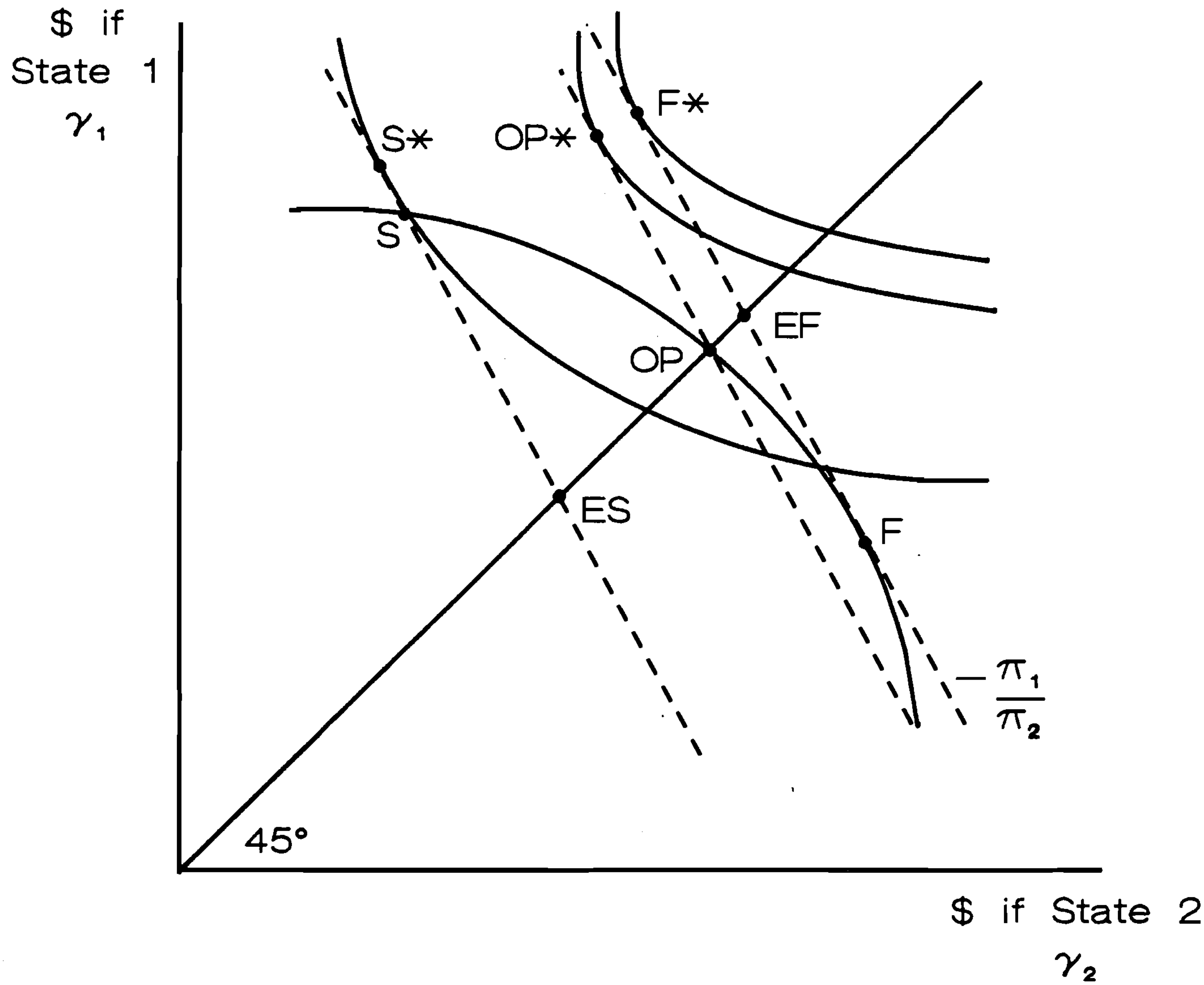

Figure 4. Fair Insurance and Stochastic Costs

- and payment possibilities limited to S and OP, the relevant measure of uncertain use benefits is the greater of S^* and OP^*, and is at least as great as ES and OP.

- and a complete array of state-conditional prices, the relevant measure of uncertain use benefits is F^* which is at least as great as EF.

Less-Than-Fair Insurance

Transactions costs tend to result in the availability of insurance only at less-than-fair prices. Less-than-fair insurance makes it impossible to attain S^*, ES, OP^*, EF, and F^*. In each case the relevant use benefit measure will be bounded by S^* and S, OP^* and OP, and F^* and WTP (note: not F), respectively.

Concluding Comments

We have shown that there are many "correct" measures of uncertain use benefits, each correct for a specific and definable set of circumstances (figure 5). Uncertain use benefits are:

• never less than OP, since the project provider can always collect OP in advance.

• never less than the greater of OP and ES, if the provider can collect pre-announced payments at the time of use and obtain fair insurance.

• bounded from below by EF when there is a complete array of state-conditional payment possibilities, stochastic costs, and fair insurance.

We have shown that the roles of state-conditional prices and insurance are quite distinct, such that F has no special merit; WTP is the correct

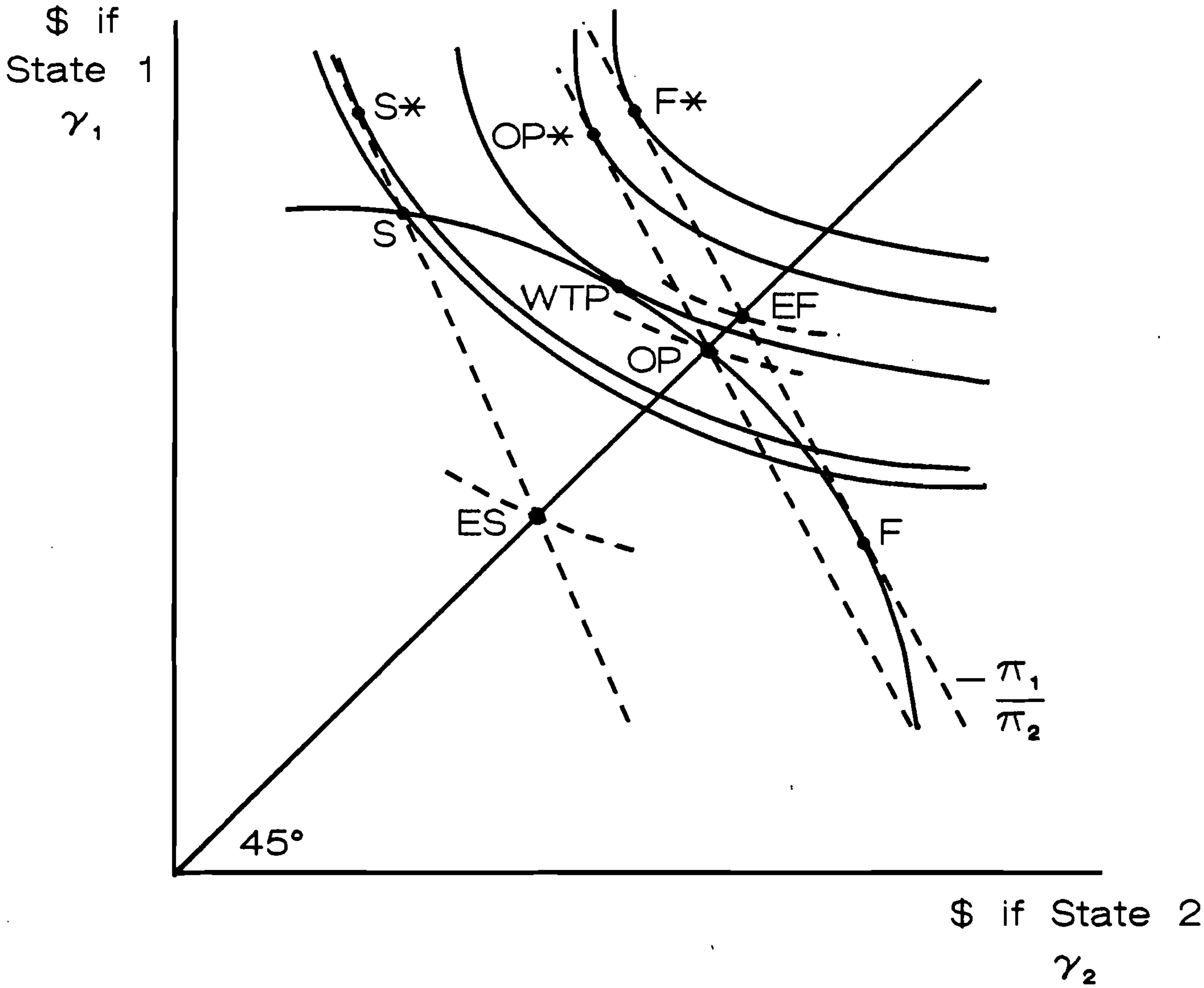

Figure 5. Use Benefits Under Uncertainty: Is There a "Correct" Measure?

measure when state-conditional payments are possible but insurance is unavailable.

The possibility that project providers would insure (or self-insure) revenue and relieve the demanders of uncertainty is, we believe, important. It serves to legitimize ES, which is a readily accessible benefit measure, as well as S^*, OP^*, and F^*, which are larger but less accessible. Often, government is the provider and, with a large and diverse portfolio, is likely to be a relatively low-cost self-insurer. Portfolio diversification is, more generally, essential to the availability of fair insurance. That is, fair insurance against localized losses requires only a modest stretching of the imagination. Fair insurance against global catastrophe is inconceivable (Marshall 1974).

Finally, we conjecture that two well-known distinctions are over-rated. First, the supply uncertainty/demand uncertainty distinction seems to boil down to a question of whether it is own-price or something else that is uncertain. Second, the *ex ante*/*ex post* distinction seems less compelling when one realizes that any point on the WTP locus (including S and OP) can be conceptualized as an *ex ante* contract to make a particular set of *ex post* payments.

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