Revisiting Cost Benefit Analysis With Supply Uncertainty

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Introduction

- Measuring benefits of an environmental improvement when there is supply uncertainty
- Motivating Example: River Restoration
  - Multiple restoration options (riparian buffers, agricultural best management practices, water treatment)
  - Many examples of failed projects, sometimes from an engineering standpoint (flooded channels, collapsing stream banks), sometimes from an ecological standpoint (fish killed or no increase in fish population)
  - Valuing river restoration projects should account for uncertainty of project success

Plan for the paper

- Discuss some theoretical issues in measuring benefits with supply uncertainty
- Develop a new empirical method of estimating benefits with supply uncertainty
- Apply empirical technique to a study of the benefits of restoring the Minnesota River Basin, a heavily polluted river which feeds into the Mississippi River in Minneapolis.

Measuring benefits with no uncertainty

- Utility is function of a composite good (c) and environmental quality (δ): $V(c, \delta)$.
- Measuring benefits of an environmental improvement from δ_0 to δ_1
- Compensating Variation (CV): $V(c_0 - CV, \delta_1) = V(c_0, \delta_0)$
- Equivalent Variation (EV): $V(c_0, \delta_1) = V(c_0 + EV, \delta_0)$

General framework with uncertainty

- N states of nature
- $\pi(s)$: probability of state s
- δ_s^f: environmental quality in state s under project f
- Assumptions
  - Endowment of c is independent of state (c_0)
  - Utility function is state independent ($V(c, \delta)$) (in contrast to demand uncertainty examples from Weisbrod [1964], Graham [1981], and others)
- $U = \sum_{s=1}^{N} V(c_0, \delta_s^f)\pi(s)$

Measuring benefits with uncertainty

- Option price is the change in income (in all states) that holds expected utility constant with or without a project.
- Compensating option price (COP):
  - Analogous to CV
  - $\sum_{s=1}^{N} V(c_0 - COP^f, \delta_s^f)\pi(s) = \sum_{s=1}^{N} V(c_0, \delta_s^0)\pi(s)$
- Equivalent option price (EOP):
  - Analogous to EV
  - $\sum_{s=1}^{N} V(c_0, \delta_s^f)\pi(s) = \sum_{s=1}^{N} V(c_0 + EOP^f, \delta_s^0)\pi(s)$

Purpose of this Paper

- Many previous papers compare compensating option price to expected CV (see Bishop [1982], Brookshire et al. [1983], Smith [1983], Freeman [1985], Smith [1985], Plummer [1986], Johansson [1988], and Bishop [1988])
- Instead, this paper compares compensating and equivalent option price and addresses the empirical estimation of these measures.

Theoretical Problems with *COP*

- When there is no uncertainty, Pauwels [1978] and Hause [1975] have shown that *EV* always correctly ranks two projects against each other but *CV* does not if change is occurring over more than one dimension.
- The same principle holds here (and even when environmental quality improvements are only measured in one dimension).
- This is important if there are two or more projects under consideration so that we can compare values relative to the status quo instead of making direct comparisons between all projects.

Theoretical Results

1. Project f is preferred to project g if and only if $EOP_f > EOP_g$.
2. $COP_f > COP_g$ does not imply that project f is preferred to project g.
3. Suppose that, if project f is preferred to project g at any arbitrary c, then project f is preferred to project g at every c. Then, project f is preferred to project g if and only if $COP^f > COP^g$.

Theoretical Problems with *COP*

Table: Ranking Multiple Alternatives Using Compensating and Equivalent Variation

	Compensating Variation	Equivalent Variation
Certain Changes over 1 dimension	Yes	Yes
Certain Changes over 2 or more dimensions	No	Yes
Uncertain Changes over 1 dimension	No	Yes
Uncertain Changes over 2 or more dimensions	No	Yes

Measuring *EOP* from certain values (*EV*)

- *EOP* for a project can be estimated relative to the status quo from certain values of equivalent variation (*EV*) along with estimates of individual risk aversion.
  - Simplifies decisions that survey respondents face.
  - Allows same study results to be used to evaluate a newly developed project.
  - Allows same study results to be used as scientific information about the probabilities of different outcomes is updated.

Measuring *EOP* from certain values (*EV*)

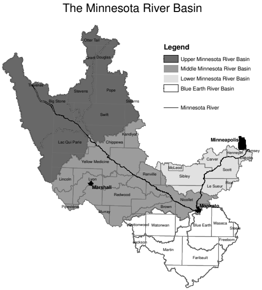
- Can rewrite *EOP* expression in terms of only δ_0 (the status quo level of environmental quality), not δ_s^f.
  1. $\sum_{s=1}^{N} V(c_0, \delta_s^f)\pi(s) = V(c_0 + EOP^f, \delta_0)$
  2. $V(c_0, \delta_s^f) = V(c_0 + EV_s^f, \delta_0)$ (for all s)
- 1 and 2 imply:
- $\sum_{s=1}^{N} V(c_0 + EV_s^f, \delta_0)\pi(s) = V(c_0 + EOP^f, \delta_0)$
- EOP^f is certainty equivalent of a money gamble that has EV_s^f as possible outcomes.
- If the individual is risk averse, EOP^f is less than the expected value of the gamble $(E(EV_s^f))$

Measuring *EOP* from certain values (*EV*)

1. Estimate EV_s^f for every possible outcome using either a contingent valuation style question or paired comparison questions
2. Assume functional form for risk preferences over money (ex. $u(c) = \frac{c^{1-r}}{1-r}$). Estimate risk preference parameter using questions similar to those in Holt and Laury [2002] or Barsky et al. [1997].
3. Combine 1 and 2 to get *EOP*.

Empirical Example

- Survey of residents who live near the Minnesota River Basin
- Minnesota River is one of most polluted rivers in U.S., with sediment, phosphorus, nitrogen, nitrates, bacteria, mercury
- Solutions: sewage treatment, agricultural best management practices, creating riparian buffers



Empirical Example

- Respondents provided bounds on their value for:
  1. A project that restored 100% of the basin for sure
  2. A project that restored 50% of the basin for sure
  3. A project that had a 50-50 chance of each of the two outcomes above
- Respondents also provided bounds on the coefficient of relative risk aversion (following Barsky et al. [1997]).

Sample Question

10. Consider a Federal money reallocation that would result in 100% of the Minnesota River Basin's surface waters having water quality high enough to support aquatic life and recreation within one year. Please answer each of the following questions. *(Please make one choice for each question)*

Question	Option A	Option B
Which would you personally prefer?	○ Federal Reallocation - 100% Basin Waters Support Aquatic Life and Recreation within 1 Year	○ Receiving a Private Gift of \$150
Which would you personally prefer?	○ Federal Reallocation - 100% Basin Waters Support Aquatic Life and Recreation within 1 Year	○ Receiving a Private Gift of \$500
Which would you personally prefer?	○ Federal Reallocation - 100% Basin Waters Support Aquatic Life and Recreation within 1 Year	○ Receiving a Private Gift of \$1000
Which would you personally prefer?	○ Federal Reallocation - 100% Basin Waters Support Aquatic Life and Recreation within 1 Year	○ Receiving a Private Gift of \$2000
Which would you personally prefer?	○ Federal Reallocation - 100% Basin Waters Support Aquatic Life and Recreation within 1 Year	○ Receiving a Private Gift of \$4000
Which would you personally prefer?	○ Federal Reallocation - 100% Basin Waters Support Aquatic Life and Recreation within 1 Year	○ Receiving a Private Gift of \$6000

Estimating EV

- $y_i^* = \alpha + \beta x_i + \epsilon_i$
- y_i^* = WTP (unobserved), y_i = observed bounds on WTP, ϵ = normal with mean 0 and variance σ^2
- $$y_i = \begin{cases} 0 & \text{if } y_i^* \leq 150 \\ 1 & \text{if } 150 < y_i^* \leq 500 \\ 2 & \text{if } 500 < y_i^* \leq 1000 \\ 3 & \text{if } 1000 < y_i^* \leq 2000 \\ 4 & \text{if } 2000 < y_i^* \leq 4000 \\ 5 & \text{if } 4000 < y_i^* \leq 6000 \\ 6 & \text{if } 6000 < y_i^* \end{cases}.$$
- $P(y_i = 0) = P(y_i^* < 150) = P(\alpha + \beta x_i + \epsilon_i < 150) = P(\epsilon_i < 150 - \alpha - \beta x_i) = \Phi((150 - \alpha - \beta x_i)/\sigma)$

Estimating EV: Log Likelihood

$$
\begin{aligned}
LL = &\sum_{y_i=0} log(\Phi(\frac{150-\alpha-\beta x_i}{\sigma}))+ \\
&\sum_{y_i=1} log(\Phi(\frac{500-\alpha-\beta x_i}{\sigma})-\Phi(\frac{150-\alpha-\beta x_i}{\sigma}))+ \\
&\sum_{y_i=2} log(\Phi(\frac{1000-\alpha-\beta x_i}{\sigma})-\Phi(\frac{500-\alpha-\beta x_i}{\sigma}))+ \\
&\sum_{y_i=3} log(\Phi(\frac{2000-\alpha-\beta x_i}{\sigma})-\Phi(\frac{1000-\alpha-\beta x_i}{\sigma}))+ \\
&\sum_{y_i=4} log(\Phi(\frac{4000-\alpha-\beta x_i}{\sigma})-\Phi(\frac{2000-\alpha-\beta x_i}{\sigma}))+ \\
&\sum_{y_i=5} log(\Phi(\frac{6000-\alpha-\beta x_i}{\sigma})-\Phi(\frac{4000-\alpha-\beta x_i}{\sigma}))+ \\
&\sum_{y_i=6} log(1-\Phi(\frac{6000-\alpha-\beta x_i}{\sigma}))
\end{aligned}
$$

Indirect Estimation of EOP

- Denote e_u^{50}, e_u^{100}, I_u, and θ_u as upper bounds on EV^{50}, EV^{100}, income, and the risk coefficient.
- Denote e_l^{50}, e_l^{100}, I_l, and θ_l as the lower bounds.
- Upper bound on EOP:
  $EOP_u = (\frac{(I_u+e_u^{50})^{1-\theta_l}}{2} + \frac{(I_u+e_u^{100})^{1-\theta_l}}{2})^{\frac{1}{1-\theta_l}} - I_u$
- Lower bound on EOP:
  $EOP_l = (\frac{(I_l+e_l^{50})^{1-\theta_u}}{2} + \frac{(I_l+e_l^{100})^{1-\theta_u}}{2})^{\frac{1}{1-\theta_u}} - I_l$

Indirect Estimation of EOP

- $$P(e^{50}, e^{100}, \theta, I) = P(EOP_u \geq y_i^* \geq EOP_l)$$
$$= P(EOP_u \geq \alpha + \beta x_i + \epsilon_i \geq EOP_l)$$
$$= \Phi(\frac{EOP_u - \alpha - \beta x_i}{\sigma}) - \Phi(\frac{(EOP_l - \alpha - \beta x_i)}{\sigma})$$
- $LL = \sum_i log(\Phi(\frac{EOP_u - \alpha - \beta x_i}{\sigma}) - \Phi(\frac{(EOP_l - \alpha - \beta x_i)}{\sigma}))$

Results

	(1)	(2)	(3)	(4)
EV^{100}	6419	5141	6753	5066
	(387.9)	(365.1)	(528.2)	(383.2)
EV^{50}	4633	1323	4857	1259
	(336.4)	(168.8)	(370.5)	(181.6)
EOP direct			5361	2368
			(372)	(254.4)
EOP indirect	5547	2865	5769	2795
	(291.9)	(218.4)	(313.2)	(227.3)
EOP indirect	5672	3445	5897	3381
(risk neutral)	(279.9)	(248.9)	(310.8)	(259)
$E(EV)$	5526	3232	5805	3163
# Obs.	451	114	400	102

- (1) Full Sample
- (2) Full Sample minus those who gave same answer for 100% and 50% restoration
- (3) Full Sample minus inconsistent choices about EOP direct
- (4) Sample (3) minus those who gave same answer for 100% and 50% restoration

Conclusions

- Advantages of *EOP*
  - Higher *EOP* implies a preferred project when comparing multiple projects.
  - *EOP* can be calculated from information on *EV* for certain improvements combined with risk preferences over money (simplified survey design, re-use data when new projects are developed)
- Empirical application limited by large number of respondents who placed 50% and 100% restoration in same interval.
- Nonetheless, results of the indirect method are close to the direct results and both are less than expected surplus as a result of risk aversion.
- Values for 50% restoration are more than half 100% restoration in the full sample (although the large number of respondents who took restoration over all dollar values influences this result).

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