AGGREGATION AND DISAGGREGATION OF PROGRAM BENEFITS IN A COMPLEX POLICY ENVIRONMENT

John P. Hoehn
and
Alan Randall

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Abstract

Benefit-cost analyses commonly treat the components of multi-part national policy as independent in valuation. A general conceptual structure for aggregation and the results of an empirical case study suggest that, in general, the independence assumption is mistaken. Specific propositions are given to guide aggregation across competitive and complementary non-rival goods.

John P. Hoehn, (A.B., Berkeley, 1972; M.S., Kentucky, 1979) is a doctoral candidate in agricultural economics at the University of Kentucky.

Alan Randall (B.S., M.S., Sydney, 1965, 1969; Ph.D. Oregon State, 1970) is a professor of agricultural economics at the University of Kentucky.

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John P. Hoehn and Alan Randall
University of Kentucky

Policy initiatives typically influence the provision of non-rival goods' services at multiple sites or regions over different periods of time. In addition, at any particular time there are usually many such multi-part policy proposals under consideration. Benefit cost (BC) analyses commonly treat these multiple impacts as independent in valuation; as if the value of non-rival goods provided by one component of policy were unaffected by the level of non-rival goods offered by another policy component. Given independence, evaluation is greatly simplified. Benefits attributable to the component elements of a policy package can be estimated independently, often in separate research efforts, and then summed to determine total program benefits. In this paper we demonstrate that this conventional approach to the BC evaluation of multi-part policy, relying as it does on the uninformed presumption of independence, is generally mistaken.

In place of conventional aggregation procedures, we develop an aggregation structure general enough to admit competition, independence, or complementarity among multiple non-rival goods. The structure described extends the special case of inter-site substitution (Burt and Brewer; Knetsch; Morey; Majid, Sinden, and Randall) to the general BC problem of valuing and aggregating valuations over policy components affecting diverse sets of non-rival goods. In the special as well as the general case, competitive and complementary (CC) relationships arise as individuals substitute toward more satisfying activities as opportunity sets change with policy. Only if

CC effects just cancel does the total valuation derived from conventional procedures equal that from the correct design.

The aggregation structures derived lead to three general conclusions regarding the BC analysis of multi-part policy. First, by applying the general aggregation structure to either contingent or demand-based valuation, unambiguous measures of total benefits are attainable. The general aggregation structure permits one-step valuation of the complete policy package via contingent valuation. Alternatively, a step-by-step valuation procedure may be implemented with contingent valuation through Proposition 3 or with demand-based analysis through Proposition 4. Second, if policy evaluation requires information about benefits attributable to the component elements of policy, a sequence of valuation must be selected and applied. That is, the components of policy must be ordered from first to last and then valued sequentially by changing one element at a time from its initial to its post-policy level. Third and finally, benefits attributable to the component elements of multi-part policy are not generally unique but are dependent upon the particular sequence of valuation selected. Only in the special case when CC effects just cancel can the problem of sequencing be ignored and the general structure reduced to conventional procedures.

The fact that disaggregate benefits are sequence dependent is especially important in light of mandates such as Executive Order 12291 which require a component by component BC justification of complex regulatory programs. If component benefits are to be meaningful to such policy evaluations, selected valuation sequences must conform to the appropriate sequence of implementation. If a program affects relatively few non-rival goods, the likely sequence of implementation may be fairly well-defined and valuation can proceed accordingly. However, as programs become more complex and as additional programs are perceived as contributions to the general augmentation of the non-rival goods vector, the planned implementation sequence becomes less definite and more obscure.

Executive Order 12291 specifically calls for the use of benefit cost analysis to identify the components for inclusion in regulatory policy packages and to establish priorities within such packages. In other words, benefit-cost analysis is required to be used in deciding, on a priority basis, the content and implementation sequence of policy packages. There is a long literature casting doubt on the theoretical possibility and practical feasibility of using benefit-cost analysis to determine optimal packages of projects and programs; the findings of Chipman and Moore (1980) are merely a significant recent contribution to this literature. Our conclusions add one more dimension to this problem set. The problem of prioritizing and sequencing acquires a kind of circularity. Component benefits depend on sequencing, but the appropriate sequence depends on benefits. Under EO 12291, the more beneficial components have highest priority. In this kind of analytical context, our conclusions suggest a painstaking iterative process toward appropriate valuation of appropriately sequenced components, with no assurance of ultimately identifying a unique optimal package.

These conclusions suggest that life would surely be easier for the benefit-cost analyst if independence in valuation was the general rule. Direct interactions between non-rival goods are eliminated in the case of additive separability between such goods in the utility functions. We show that additive separability leads to unambiguous competitive relationships. In the absence of additive separability, CC effects are generally to be expected, but the possibility exists that complementary effects may on occasion outweigh competitive effects. Except in cases where complementary and competitive effects just happen to cancel, independence in valuation will not occur.

The case of additive separability in which the relationship among non-rival goods is unambiguously competitive is empirically significant. In particular, we discuss two fairly typical BC contexts in order to demonstrate how additive separability might arise. We are confident, however, that these two cases by no means exhaust the set of applied cases to which additive separability is relevant.

We apply our theoretical results in a contingent valuation study of visual air quality programs affecting distinct geographic regions of the United States. Theoretical considerations lead to the prediction of unambiguous competitive effects among regional programs. Empirical results confirm this prediction. Furthermore, the error introduced by independent valuation was found to be statistically significant and economically consequential.

Given our theoretical conclusion that CC effects are general and an empirical finding in which such effects had a sizeable influence on benefit estimates, we conclude that the caveats implied by the general aggregation structure are worthy of the attention of theoreticians and practictioners.

Having stated our conclusions in advance, and discussed their implications for BC practice, we now proceed with the theoretical development, followed by an empirical case study.

A Conceptual Structure for Aggregation

Our conceptual structure is based on the expenditure function. Through the expenditure function the resulting aggregation structure can be linked with Hicksian demand concepts and their approximations (Willig 1976, 1979; Randall and Stoll), contingent valuation (Randall, Ives, and Eastman; Brookshire, Randall, and Stoll), the bid-rent function of hedonic price theory (Rosen, Anas), welfare measurement in a quantal choice framework (Small and Rosen), and exact consumer's surplus (Hausman).

To begin, consider a household that gains satisfaction from a vector of activities, $a=(a_1,\ldots,a_I)$. Production of activity a_i is given by

(1) $$a_i = a_i(x_i,q_i,\alpha) \qquad 0 \leqq a_i(0,q_i,\alpha), \quad 0 \leqq a_i(x_i,0,\alpha),$$

where $i\varepsilon\{1,\ldots I\}$, x_i is a private market good (or Hicksian composite) with price p_i, q_i is an unpriced non-rival good, α is the household's relevant human capital, and the a_i are increasing and strictly concave.[1] Given production possibilities, prices $p = (p_1,\ldots,p_I)$, and non-rival goods' levels $q = (q_1,\ldots,q_I)$, an indirect utility function is defined by

(2) $$v(p,q,\alpha,m) = \max_x u(a) \quad \text{s.t. } m = px,\ a = [a_i(x_i,q_i,\alpha)]$$

where $x = (x_1,\ldots,x_I)$, m is income, and utility function, u(a), is increasing, continuous, and strictly quasiconcave. The expenditure function is

(3) $$e(p,q,\alpha,u) = \min_{x} px \quad \text{s.t. } u = u(a),\ a = [a_i(x_i,q_i,\alpha)]$$

where $m = e(p,q,\alpha,v(p,q,\alpha,m))$

With the initial or pre-policy levels of the non-rival goods at $q^0 = (q_1^0,\ldots,q_I^0)$, a household attains utility $u^0=v(p,q^0,\alpha,m)$. The marginal compensating variation (Randall and Stoll (1980 a, b); Brookshire, Randall, and Stoll) of a program that affects a single non-rival good, q_i, is the direct derivative of equation (3) with respect to q_i,[2]

(4) $$\partial e(p,q_1^0,\ldots,q_i^0,\ldots,q_I^0,u^0)/\partial q_i = -\lambda \partial u/\partial q_i \partial a_i/\partial q_i < 0$$

where λ is the Lagrangian multiplier associated with the contraint $u = u(a)$ in equation (3). By equation (4) the individual is willing to pay a small amount of initial expenditure, $m = e(p,q^0,u^0)$, to get a small change in q_i^0. The total compensating variation associated with the policy increment from q_i^0 to q_i^1 is

(5) $$\begin{aligned}&\int_{q_i^0}^{q_i^1} \partial e(p,q_1^0,\ldots,\delta_i,\ldots,q_I^0,u^0)/\partial\delta_i\, d\delta_i\\ &\equiv e(p,q_1^0,\ldots,q_i^1,\ldots,q_I^0,u^0) - e(p,q_1^0,\ldots,q_i^0,\ldots,q_I^0,u^0)\\ &\equiv e(p,q_1^0,\ldots,q_i^1,\ldots,q_I^0,u^0) - m\\ &\equiv CS(q^1,q^0,u^0)\end{aligned}$$

Located in the real plane with (q^0,m) as the origin, $m-e(p,q_1^0,\ldots,q_i^1,\ldots,q_I^0,u^0)$ describes an indirect version of the Bradford bid curve. Except for algebraic sign equation (5) describes precisely the outcome of a contingent valuation experiment as in Randall, Ives, and Eastman.

With equations (4) and (5) as fundamental definitions, consider a multi-part policy that changes $q^0=(q_1^0,\ldots,q_I^0)$ to $q^1=(q_1^1,\ldots,q_I^1)$. Total surplus from the program q^0 to q^1 is the line integral [3]

(6)
$$\int_C \partial e(p,q_1,\ldots,q_i,\ldots,q_I,u^0)/\partial\delta d\delta$$

$$\equiv e(p,q_1^1,\ldots,q_i^1,\ldots,q_I^1,u^0) - e(p,q_1^0,\ldots,q_i^0,\ldots,q_I^0,u^0)$$

where C denotes some path from q^0 to q^1. Because the integral in equation (6) is path independent, <u>total</u> variation is uniquely defined. Total compensating variation depends only upon the beginning (q^0) and ending (q^1) values of q and not upon a intermediate sequence of component changes. However, the value of a change in an individual program component from q_i^0 to q_i^1 is not, in general, uniquely defined. Component variations depend upon the choice of a particular path or sequence of valuation. Therefore, component valuations of the changes from q_i^0 to q_i^1 only become meaningful when a particular rectangular path from q^0 to q^1 is chosen. For example, choosing a path or sequence of valuation from $q^0=(q_1^0,q_2^0,q_3^0,\ldots,q_I^0)$ to $(q_1^1,q_2^0,q_3^0,\ldots,q_I^0)$ to $(q_1^1,q_2^1,q_3^0,\ldots,q_I^0)$ to $(q_1^1,q_2^1,q_3^1,\ldots,q_I^0)$ until all I quality levels are affected at $q^1=(q_1^1,q_2^1,q_3^1,\ldots,q_I^1)$ the line integral in equation (6) can be transformed to I ordinary integrals,

(7) $$CS(q^1,q^0,u^0) \equiv e(p,q^1,u^0) - e(p,q^0,u^0)$$

(7.1) $$\equiv \int_{q_1^0}^{q_1^1} \partial(p,\delta_1,q_2^0,q_3^0,\ldots,q_I^0,u^0)/\partial\delta_1 d\delta_1$$

(7.2) $$+ \int_{q_2^0}^{q_2^1} \partial(p,q_1^1,\delta_2,q_3^0,\ldots,q_I^0,u^0)/\partial\delta_2 d\delta_2$$

(7.3) $$+ \int_{q_3^0}^{q_3^1} \partial e(p,q_1^1,q_2^1,\delta_3,\ldots,q_I^0,u^0)/\partial\delta_3 d\delta_3$$

(7.4) $$+\ldots+ \int_{q_I^0}^{q_I^1} \partial e(p,q_1^1,q_2^1,q_3^1,\ldots,\delta_I,u^0)/\partial\delta_I d\delta$$

Selecting an alternative rectangular path that reverses the path of equation (7) by changing q_I^0 to q_I^1 first, q_{I-1}^0 to q_{I-1}^1 second, until lastly changing q_1^0 to q_1^1 , results in the same aggregate valuation but in generally different incremental valuations associated with the q_i;

(8) $$CS(q^1,q^0,u^0) \equiv e(p,q^1,u^0) - e(p,q^0,u^0)$$

(8.1) $$\equiv \int_{q_1^0}^{q_1^1} \partial e(p,\delta_1,q_2^1,q_3^1,\ldots,q_I^1,u^0)/\partial\delta_1 d\delta_1$$

(8.2) $$+ \int_{q_2^0}^{q_2^1} \partial e(p,q_1^0,\delta_2,q_3^1,\ldots,q_I^1,u^0)/\partial\delta_2 d\delta_2$$

(8.3) $$+ \int_{q_3^0}^{q_3^1} \partial e(p,q_1^0,q_2^0,\delta_3,\ldots,q_I^1,u^0)/\partial\delta_3 d\delta_3$$

$$(8.4) \qquad +\ldots+\int_{q_I^0}^{q_I^1} \partial e(p,q_1^0,q_2^0,q_3^0,\ldots,\delta_I,u^0)/\partial\delta_I d\delta_I$$

In general, unless $\partial e/\partial q_i\partial q_j=0$ for all $i\neq j$, it is true that (7.1) $\neq$ (8.1), (7.2) $\neq$ (8.2), (7.3) $\neq$ (8.3), and (7.4) $\neq$ (8.4). Thus, we have:

> Proposition 1. Let q be a I dimensional vector of non-rival goods. Consider the change from q^0 to q^1 along the I! polygonal sequences of valuation determined by changing q_i^0 to q_i^1 one element, q_i, at a time. If $\partial^2 e/\partial q_i\partial q_j\neq 0$ for some $i\neq j\varepsilon\{1,\ldots,I\}$, the value of a component change, q_i^0 to q_i^1, may vary with the I! possible sequences of valuation. If $\partial^2 e/\partial q_i\partial q_j=0$ for all $i\neq j\varepsilon\{1,\ldots,I\}$ the value of a component change, q_i^0 to q_i^1, is invariant.

If the non-rival goods, q_i, are competitive in valuation ($\partial^2 e/\partial q_i\partial q_j>0$, for all $i\neq j$), the value of a component change from q_i^0 to q_i^1 is larger the earlier q_i appears in the sequence of valuation. If the q_i are complementary ($\partial^2 e/\partial q_i\partial q_j<0$, for all $i\neq j$), then the component benefit of a change in q_i is smaller the earlier it appears in the valuation sequence. Only if all q_i and q_j are independent ($\partial^2 e/\partial q_i\partial q_j=0$, for all $i\neq j$) component valuations invariant with changes in sequence. Therefore, only if non-rival goods are independent, can a valuation of the policy vector ignore the problem of selecting an appropriate path.

Suppose, however, that goods are competitive but we proceed as if valuations of the component changes, q_i^0 to q_i^1, were independent. We would measure

$$(9.1)\qquad V(q^1,q^0) = e(p,q_1^1,q_2^0,q_3^0,\ldots,q_I^0,u^0) - e(p,q_1^0,q_2^0,q_3^0,\ldots,q_I^0,u^0)$$

$$(9.2)\qquad + e(p,q_1^0,q_2^1,q_3^0,\ldots,q_I^0,u^0) - e(p,q_1^0,q_2^0,q_3^0,\ldots,q_I^0,u^0)$$

$$(9.3)\qquad + e(p,q_1^0,q_2^0,q_3^1,\ldots,q_I^0,u^0) - e(p,q_1^0,q_2^0,q_3^0,\ldots,q_I^0,u^0)$$

$$(9.4)\qquad +\ldots+ e(p,q_1^0,q_2^0,q_3^0,\ldots,q_I^1,u^0) - e(p,q_1^0,q_2^0,q_3^0,\ldots,q_I^0,u^0)$$

$$(9.5)\qquad \neq e(p,q_1^1,q_2^1,q_3^1,\ldots,q_I^1,u^0) - e(p,q_1^0,q_2^0,q_3^0,\ldots,q_I^0,u^0)$$

A well conceived valuation strategy would recognize the non-independence of the q_i, select a rectangular policy path corresponding to the sequence of the actual policy under consideration (say, for example, the path in (7), and obtain [4]

$$(10)\qquad CS(q^1,q^0,u^0) \equiv e(p,q_1^1,q_2^1,q_3^1,\ldots,q_I^1,u^0) - e(p,q_1^0,q_2^0,q_3^0,\ldots,q_I^0,u^0)$$

$$(10.1)\qquad \equiv e(p,q_1^1,q_2^0,q_3^0,\ldots,q_I^0,u^0) - e(p,q_1^0,q_2^0,q_3^0,\ldots,q_I^0,u^0)$$

$$(10.2)\qquad + e(p,q_1^1,q_2^1,q_3^0,\ldots,q_I^0,u^0) - e(p,q_1^1,q_2^0,q_3^0,\ldots,q_I^0,u^0)$$

$$(10.3)\qquad + e(p,q_1^1,q_2^1,q_3^1,\ldots,q_I^0,u^0) - e(p,q_1^1,q_2^1,q_3^0,\ldots,q_I^0,u^0)$$

$$(10.4)\qquad +\ldots+ e(p,q_1^1,q_2^1,q_3^1,\ldots,q_I^1,u^0) - e(p,q_1^1,q_2^1,q_3^1,\ldots,q_I^0,u^0)$$

In equations (9) and (10) only R.H.S. lines (9.1) and (10.1) are equal. In the assumed case of substitutes, (9.2) is larger in absolute value than (10.2), (9.3) is larger in absolute value than (10.3), and, finally, (9.4) is larger in absolute value than (10.4).

<u>Proposition 2</u>. If $\partial^2 e/\partial q_i \partial q_j \neq 0$ for all $i \neq j$, the value of a change in the vector $q = (q_1,\ldots,q_I)$ is generally <u>not</u> equal to the sum of the independently estimated values of the changes in individual elements, q_i, of the vector q.

Clearly if the goods q_i are competitive, $V(q^1,q^0)$ overstates the actual value as given by $CS(q^1,q^0,u^0)$.[5] If goods q_i are complementary, $V(q^1,q^0)$ understates $CS(q^1,q^0,u^0)$. Only if the non-rival goods q_i are independent do the values elicited in lines (9.1) through (9.4) equal the values derived through the correct design given in equation (10).

Equation (10) provides a general design for valuing a program which would change the level of each of I non-rival goods. However, if component valuations are to be meaningful the design requires explicit ex ante specification of the sequence in which individual components of q are to be augmented. If a sequence of implementation is meaningful and can be communicated within a contingent valuation structure, then both total and component valuations are obtainable through contingent valuation.

Proposition 3. If the change induced by a multi-part policy is identified by a change in non-rival goods levels from $q=(q_1^0,\ldots,q_I^0)$ to $q^1=(q_1^1,\ldots,q_I^1)$, then identities (10) describe a general aggregation structure for determining, through contingent valuation (e.g., Brookshire, Randall, and Stoll; Randall, Ives and Eastman) both the total and component compensating variations induced by such a policy.

Two important points can be drawn from Proposition 3. First, by identity 10, a total valuation of a multi-part policy is unambiguous and depends only upon initial, q^0, and subsequent, q^1, levels of non-rival goods. Through contingent valuation it is therefore always conceptually possible to elicit in a single iteration a total valuation of multi-part policy without resorting to a valuation of the component parts. Second, by applying Proposition 1 to Proposition 3, selection of a particular valuation sequence is crucial to obtain generally valid component valuations. Any polygonal path of changes q_i^0 to q_i^1 from q^0 to q^1 would conform to the requirements of Proposition 3. However, in application the choice set of possible sequences may be restricted to those relevant to feasible sequences of policy implementation.

In some cases it is possible to estimate the compensating variation associated with a change in non-rival goods, q, with information contained in the Hicksian demands (or approximations) for market goods, $x(p,w,u) = \partial e/\partial p$. Mäler's work with a single priced good demand is seminal. Recent work has extended this approach to quantal choice (Small and Rosen) and the valuation of multiple non-rival goods through multiple private goods demands (Bradford and Hildebrant). Our general structure (7) can be extended to establish a rule for correct sequential valuation of the component parts of a multi-part policy through analysis of market demands.

A sufficient condition for valuation of non-rival goods via market demands is "weak complementarity" (Mäler). To make use of weak complementarity in valuing K < I non-rival goods, equation (1) must be modified to allow $0 = a_i(0,q_i,\alpha)$. We must also suppose that there exists a set of prices, $p^1=(p_1^1,\ldots,p_K^1)$, at which the individual is unaffected by changes in non-rival goods levels $q=(q_1,\ldots,q_K)$. If p^1 is high enough, weak complementarity requires that (Small and Rosen)

(11) $$\partial e[(\ldots,p_k^1,\ldots),(\ldots,q_k,\ldots),u^0]/\partial q_k = 0.$$

Using the definition of Hicksian demands, $\partial e/\partial p = x(p,q,u)$ and equation (11) each of the first lines in equation (7) can be replaced by

(12)
$$\int_{q_k^0}^{q_k^1} e(p_1,\ldots,p_k,\ldots,p_K,q_1^1,\ldots,\delta_k,\ldots,q_K^0,u^0)/\partial\delta_k d\delta_k$$
$$\equiv \int_{p_k}^{p_k^1} [x_k(p_1,\ldots,\rho_k,\ldots,p_K,q_1^1,\ldots,q_k^0,\ldots,q_K^0,u^0) - x_k(p_1,\ldots,\rho_k,\ldots,p_K,q_1^1,\ldots,q_k^1,\ldots,q_K^0,u^0)]d\rho_k$$

Proposition 4. If the change induced by a multi-part policy is described by a change in non-rival goods' levels from $q^0=(q_1^0,\ldots,q_K^0)$ to $q^1=(q_1^1,\ldots,q_K^1)$, K<I, and if there exist prices, $p^1=(p_1^1,\ldots,p_K^1)$, high enough such that equation (11) holds for all q_k, then an aggregation structure for determining both the total compensating variation and the variations generated by components is

$$CS(q^1,q^0,u^0) \equiv \int_{p_1}^{p_1^1} [x_1(\rho_1,p_2,p_3,\ldots,p_K,q_1^0,q_2^0,q_3^0,\ldots,q_K^0,u^0) - x_1(\rho_1,p_2,p_3,\ldots,p_K,q_1^1,q_2^0,q_3^0,\ldots,q_K^0,u^0)]d\rho_1$$
$$+ \int_{p_2}^{p_2^1} [x_2(p_1,\rho_2,p_3,\ldots,p_K,q_1^1,q_2^0,q_3^0,\ldots,q_K^0,u^0) - x_2(p_1,\rho_2,p_3,\ldots,p_K,q_1^1,q_2^1,q_3^0,\ldots,q_K^0,u^0)]d\rho_2$$
$$+ \int_{p_3}^{p_3^1} [x_3(p_1,p_2,\rho_3,\ldots,p_K,q_1^1,q_2^1,q_3^0,\ldots,q_K^0,u^0) - x_2(p_1,p_2,\rho_3,\ldots,p_K,q_1^1,q_2^1,q_3^1,\ldots,q_K^0,u^0)]d\rho_3$$

$$+\ldots+\int_{p_K}^{p_K^1}[x_K(p_1,p_2,p_3,\ldots,\rho_K,q_1^1,q_2^1,q_3^1,\ldots,q_K^0,u^0)$$
$$-\, x_K(p_1,p_2,p_3,\ldots,\rho_K,q_1^1,q_2^1,q_3^1,\ldots,q_K^1,u^0)]d\rho_K$$

where the $x_k(p,q,u)$ are the Hicksian market goods demands which, by assumption, satisfy equation (12), and where $p=(p_1,\ldots,p_K)$ are the initial prices of the market goods.

By Proposition 4 the structure for policy evaluation through market goods demands is more restrictive than the structure for contingent valuation. The most important restriction is that a single, one step aggregate valuation is not possible as it is with contingent valuation (as in first line of identity 10). Because a total valuation is obtainable only by summation of the components valuations the caveats on the contingent valuation of the component elements of policy apply even more strongly to the market goods' demands case.

Proposition 4 provides a structure for total program valuation by aggregating over the values of component changes. Whether or not component valuations are meaningful to policy evaluation depends upon whether the sequence of valuation corresponds to the intended sequence of implementation. Provided that an actual implementation sequence can be specified, valuation procedures should correspond to that sequence.

Propositions 3 and 4 impose substantial information requirements on policy evaluation. If it were possible to show either (1) conceptual support for general independence in valuation or (2) empirical evidence that competition (or complementarity) is generally of trivial magnitude, then applied research would be greatly simplified. Evaluation of the K effects of policy would reduce to K independent evaluations; total benefits would become a simple summation of the K independent elements.

On the Possibility of Independence in Valuation

Conventional BC procedures are clearly appropriate in situations where independence in valuation can be demonstrated. Thus, while competitive and complementary relationships arising from price changes are frequently observed, it is important to consider the possibility that general and empirically significant cases may exist in which CC effects are absent or weak for changes in non-rival goods. As an appealing possibility, intuition may suggest the case where non-rival goods are additively separable in the utility function. In this case, Proposition 5 applies.

Proposition 5. Let preferences of an individual be represented by an additively separable utility function,

$$u = \sum_{i=1}^{I} \sum_{k=1}^{K} v_i(x_k, q_k)$$

where $x_k=(x_{kg})$ is a G-dimensional vector of market goods, $q_k=(q_{kh})$ is an H-dimensional vector of non-rival goods, $k\varepsilon\{1,\ldots,K\}$ indexes subcategories of market and non-rival goods used in v_i, the v_i are each increasing and strictly concave with non-negative second-order cross partial derivatives, and $\partial q_k/\partial q_f=0$ for $k\neq f\varepsilon\{1,\ldots,K\}$. Let

$$e(p,q_1,\ldots,q_K,u) = \min_x px \quad \text{s.t. } u = \sum_{i=1}^{I} \sum_{k=1}^{K} v_i(x_k, q_k)$$

Then the following properties hold:

(1) For non-rival goods in different subcategories ($k \neq f$) the substitution relationship is competitive ($\partial^2 e/\partial q_{kh}\partial q_{fr} > 0$, all h and r).

(2) For non-rival goods in the same subcategory the substitution relationship may be either competitive, independent, or complementary ($\partial^2 e/\partial q_{kh}\partial q_{kr} \gtreqless 0$, all h and r).[6]

Proposition 5 demonstrates that independence in valuation does not arise from additive separability. Indeed, the case of additive separability between non-rival goods results in unambiguous competitive effects. Applying Propositions 1 to 4 to this case, the sum of independently estimated component benefits would exceed the total benefits of a correctly valued policy package.

Where additive separability cannot be assumed, competitive and complementary effects are both conceptually possible. Thus, the possibility exists that, on occasion, complementary effects may outweigh competitive effects. Less likely still is the case where competitive and complementary effects just cancel and result in independence in valuation.

Given the implications of Proposition 5, it is useful to consider the empirical circumstances that may justify additive separability between non-rival goods. Below, we examine two possible cases; the first where an individual enjoys equivalent activities each affected by different sets of non-rival goods and the second where future use is uncertain. While merely indicative and not intended to exhaust the set of possible applications, the cases considered are easily linked to common BC contexts. Thus interpreted, Proposition 5 provides an a priori prediction of competitive effects and underscores the importance of a correct BC design.

Consider the first case where the household production technology for activity i is not specific to a particular site or region k. Market goods, x_k, and non-rival goods, q_k, available at site or region k enter as inputs into the production technology and $a_{ik}=a_i(x_k,q_k)$. Within a given time period total activity production of type a_i is a simple summation over all visited sites or regions k, $a_i=\sum_{i=1}^{k} a_i(x_k,q_k)$. If preferences are defined over a similar time period (say, a month or a year) utility can be written

$$
\begin{aligned}
(13) \qquad u &= u[a_i,\ a(x,\omega)] \\
&= u[\sum_{i=1}^{K} a_i(x_k,q_k), a(x,\omega)]
\end{aligned}
$$

where a(.) is a vector of other activities, x is a vector of market goods, and ω is a vector of non-rival goods specific to a(.). If activities a_i are broadly defined and do not directly and strongly affect the enjoyment of other activities $(\partial^2 u/\partial a \partial a_i \simeq \jmath \cdot (\text{a constant}))$ then utility is approximated by

$$
(14) \qquad u = \sum_{i=1}^{K} a_i(x_k,q_k) + \jmath' a(x,\omega)
$$

where $\jmath$ is a vector of ones conformable to $a(x,\omega)$. On grounds of convenience, additive separability as in equation (15) is a common assertion in both economic theory and econonometrics (Deaton and Muelbauer). Moreover, in this case of equivalent activities over different sites or regions, additive separability appears to have strong intuitive appeal. For instance, enjoyment of slack water recreation at site k is not likely to be directly affected by water quality at site m; snowskiing activities at site n are not likely to be directly affected by the slopes available at site p.[7]

A second source of dominating additivity comes from the rationale underlying option demand and option price. Consider a simple case where an individual faces the future possibility of either recreating within the region of residence or visiting one of two fairly unique but distant recreation areas. By unique we mean to imply the possibility of activity production technology peculiar to the recreation itself. For an easterner, candidate areas might be the Grand Canyon National Park or Yellowstone National Park; for a westerner, the Maine coast or the Florida everglades might be appropriate. If the areas are indeed distant and quite costly to visit relative to home region alternatives, the probability of future use is likely to be small and dominated by exogenous random elements rather than explicit individual choice. With probabilities of visitation parametric to the individual at the time of valuation, the expected utility model can be meaningfully applied.[8] Supposing the conventional additive utility structure over time, expected utility in future period to is

$$(15) \qquad u_t = u_t\Big[\underline{\sum^{3}}\ \pi_{tk} \circ z_{tk}(x_{tk}, q_{tk})\Big]$$

where $\underline{\sum^{3}}$ denotes a lottery over the three described possibilities, k=1,2,3, and π_{tk} is the probability that in time period t recreational activity z_{tk} is chosen. For simplicity, suppose there is only one future period and that we can therefore suppress the notation t. Using the expected utility property,

$$u = \sum_{k=1}^{3} \pi_k u[z_k(x_k, q_k)] \tag{16}$$

$$= \sum_{k=1}^{3} \pi_k u_k(x_k, q_k)$$

where $\sum_{k=1}^{3}$ denotes arithmetic summation. Thus, the case of parametric uncertainty leads to additive independence between activities and respective non-rival goods by a fairly direct route.

Proposition 5 is straightforwardly translated into the two valuation contexts detailed above. In the context of equivalent activites at different sites or in different regions, let $v_1(.)=a_i(.)$ and let the $v_2(.),...,v_I(.)$ equal the respective I-1 elements of $a(x,\omega)$. Subcategory indexes conform to the site or region specific indexes of the market and non-rival goods used in $v_1(.)$. By Proposition 5, then, non-rival goods used in equivalent activities but located in different regions are competitive in valuation. Non-rival goods used in the same activity at the same site or region may be competitive, independent, or complementary. To translate Proposition 5 into the case of uncertain visitation, let K=3, $v_i(.)=\pi_k u_k(.)$, and eliminate the summation over i. The subcategories index services specific to an area k. As in the case of equivalent activities, non-rival goods, changes are competitive across regions but may be either competitive, independent, or complementary within the same region.

In summary, the apparent characteristics of a given choice context can lead the analysis to additive separability as the dominating structure between activities and categories of non-rival goods in the utility function. However, additive separability between activities in the utility function does not lead to independence in valuation. Quite the contrary. Given a compensated change in the level of some non-rival good, an individual maintains constant utility with reduced expenditure by shifting activity production toward the relatively more productive activities and away from the relatively less productive. Without direct complementary effects to intervene, activities with constant non-rival goods become relatively less productive. As individuals shift inputs away from these less productive activities, the value of associated non-rival goods declines. Thus, where non-rival goods are additively separable in utility, constrained expenditure minimization imposes strictly competitive cross-quality valuation effects.

An Empirical Case Study

During 1980 and 1981 a contingent valuation study of visual air quality allowed us to develop and test the implications of Proposition 5. Because the study involved Chicago residents and a valuation of visibility over the region surrounding Grand Canyon National Park (GCNP), the valuation context paralleled quite closely the case of uncertain future visitation.[9]

Valuation experiments were conducted with two different samples of Chicago residents. In the first, respondents were asked to value an increment in GCNP visibility as a single, independent component of policy. In the second sample, respondents considered a three-part policy to improve visibility over three broad areas: (1) metropolitan Chicago, (2) the eastern United States, and (3) the region surrounding GCNP. In this second policy, the increment in visibility over GCNP was described as the third component of the three-part policy. In both experiments the increments in GCNP visibility proposed by policy were identical.

Because the described context of uncertain future visitation rules out independence or complementarity, the appropriate null hypothesis states the effects of independence or complementarity on the valuation of GCNP visibility. An alternative hypothesis consistent with competitive effects is

> H_A: The value of a program to improve visual air quality in the area of GCNP is greater if measured independently than if measured in a sequence which first considers programs for metropolitan Chicago and the eastern portion of the United States.

Results of the hypothesis test are interesting for both their statistical and economic significance. Table 1 compares the results of the first sample with the results of the experiment which placed GCNP visibility third in the valuation sequence. With a t-statistic of 35 for the difference between means, the null hypothesis is clearly rejected statistically. Furthermore, with the mean independent valuation over five times larger than the sequenced valuation, competitive effects are also of clear economic significance.

To correct for other factors which might influence variation, the hypothesis test was also performed in a regression context. In regression, the dummy variable SEQUENS was used to identify independent valuation (SEQUENS=0) and sequential valuation (SEQUENS=1). From the results in Table 2, it is quite clear that the coefficient on SEQUENS is large and significant. Thus, the null hypothesis is again rejected on grounds of both statistical and economic significance.

Table 1. Sample Statistics for Valuations Associated with the Grand Canyon Visibility Programs

Valuation Type	Sample Size	Mean ($)	Standard Error
Independent	130	90.97	15.28
Last in Sequence	58	15.52	6.52

Table 2. Independent Versus Sequential Valuations; A Regression Test

Dependent Variable: Elicited Valuation for Grand Canyon Program		DFE: 162	F-Ratio Prob>F R-Square	3.15 0.0039 0.1198
Independent Variables	Parameter Estimate	Standard Error	T-Ratio	Prob>|T|
Intercept	38.59	40.59	0.95	0.34
Income	1.02	.75	1.36	0.18
Respondent<35 Years Old	9.37	29.60	0.32	0.75
Respondent≥ 55 Years Old	-30.58	32.11	-0.95	0.34
Respondent completed ≤ 12 years school	2.48	26.82	0.09	0.93
Respondent completed some graduate school	-3.75	34.89	-0.11	0.91
Citpay*	59.74	24.23	2.47	0.01
SEQUENS	-70.24	25.93	-2.71	0.01

*Respondent has no objection to the notion of citizens contributing to costs of pollution abatement.

FOOTNOTES

1. The analysis using scalars x_i and q_i can be extended to cases involving vector terms or to cases where multiple activities are affected by the same non-rival good. Such extensions require a slightly more involved narrative while the basic structure of remains unaffected. See Hoehn.

2. The notational shorthand $\partial e(p,q^0,u^0)/\partial q_i$ is used for $\partial e(p,q,u)/\partial q_i|_{q_i^0,u^0}$. At this point we also suppress the term α, letting $e(p,q,u) \equiv e(p,q,\alpha,u)$.

3. Use of the line integral as a means of aggregating over multiple demands dates to Hotelling. However, the full implications of the line integral concept in a multi-part policy context have not been discussed.

4. Equation (10) is obtained by integrating the terms in lines (7.1) through (7.4) and by applying the definition of value given in equation (5).

5. Burt and Brewer noted the possibility of competitive effects in applications of the travel cost valuation technique. They observed that "...applications have merely assumed independence... If services emanating from various outdoor recreation sites are competitive among one another in an aggregate sense, such applications will yield estimated values that are biased upward." (p. 819)

6. Proof of Proposition 5 follows from the comparative static properties of the additively separable utility function. A full proof is given in Hoehn.

7. In a similar context Domencich and McFadden characterize additive separability as a "good general working hypothesis" (p. 40).

8. The context described corresponds fairly closely to Malinvaud's case of "individual risks." Graham argues that in this case option price is a lower bound on the correct BC measure of value.

9. Visual air quality or visibility was represented using the techniques of Schulze, et al. For a more complete description of procedures and results, see Randall, Hoehn, and Tolley, and Tolley, et al.

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