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A THEORY OF BENEFIT COST ANALYSIS FOR COMPLEX REGULATORY PROGRAMS

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Abstract

Current policies call for increasingly prominent use of benefit cost (BC) information in the analysis of regulatory initiatives and public policy. Initial research has shown that, for complex policy packages requiring aggregation and disaggregation of component benefits, conventional BC procedures are generally invalid. The most prevalent result is overestimation of total program benefits and misidentification of regulatory priorities. Exact aggregation rules have been derived, but these are not always readily incorporated into field procedures.

Research objectives are (1) to complete the theoretical analysis of the impact of competitive and complementary relationships among program components on BC outcomes; (2) to examine possible asymmetries between measures of benefit and cost; (3) to derive generalized necessary and sufficient conditions for the valid aggregation of benefits and costs; (4) to develop empirical approximations to the exact aggregation design; and (5) to evaluate the conventional procedures in terms of optimality and satisfactoriness as BC indicators.

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Chapter I

PROSPECTS FOR AN IMPROVED BENEFIT COST DESIGN

Regulatory analysis has acquired a substantial benefit cost component. Once largely restricted to the evaluation of Federal flood and water control projects, benefit cost analysis is now applied to policies of national scope and impact. The complexity of such national regulatory initiatives raises special problems for benefit cost design.

In decades prior to the 1960's, mandated use of benefit cost analysis was limited to projects authorized under the Flood Control Act of 1936. Projects evaluated under the 1936 mandate typically fell short of a national impact. By the end of the 1960's, however, benefit cost information had entered the realm of general regulatory analysis [Andrews]. During the 1970's, as part of a growing effort to control the regulatory process, BC evaluation became increasingly accepted in the assessment of regulatory proposals [White, Andrews]. By 1980, BC techniques had been applied to a wide range of environmental and regulatory programs.

Executive Order (EO) 12291 of 1981 sanctioned the general regulatory role of benefit cost information. EO 12291 required that all major regulatory initiatives originating in the Federal executive branch be evaluated and prioritized on the basis of benefit cost information. Most significantly, EO 12291 required the use of BC information to distinguish acceptable and unacceptable policy actions. EO 12291 mandated that major regulatory action "not be undertaken unless the potential benefits outweigh the potential costs" [Presidential Documents, p. 125].

The benefit cost task under EO 12291 is complex. Policy now subject to BC evaluation is likely to be a broad set of institutional and structural changes with multiple and interrelated impacts. The conventional model of benefit cost design, however, appears more appropriate to the bygone context of an isolated, single impact water control project. A conventional approach to BC design typically partitions a broad, wide-ranging policy initiative into its component parts and evaluates each component impact in isolation and without reference to the overall impact of policy. Component impacts are commonly assessed by different and independent research teams. With each impact evaluated in isolation, even obvious sources of substitution and complementarity tend to be ignored [cf., Fraas]. Where an overall valuation is required, it is obtained by simple summation of the independently obtained benefits and costs.

The reliability of the conventional BC approach to complex policy is suspect on both apriori and empirical grounds. Economic theory routinely asserts the complementary and competitive effects of market price changes. Such cross price effects as well as analogous effects between the nonmarket impacts of policy cannot be accounted for in independent evaluations of the component impacts. Recent empirical work by Hoehn and Randall, Lave, and Braeutigam and Noll demonstrates that failure to account for such substitution effects does indeed introduce substantial error into conventional benefit cost analyses. Thus, in at least these cases, the conventional design fails as reliable guide to policy evaluation.

The primary objective of this study is to improve the design of routine benefit cost evaluation. As a first step, a generally valid design will be developed. The theoretical structure of the valid design will then be used to generalize the comparison of conventional and valid BC outcomes and to determine the conditions in which conventional methods are likely to err.

Finally, the problem of empirically implementing a valid design will be considered in light of the likely resource constraints on evaluation.

The Conceptual Basis of Benefit Cost Evaluation

BC analysis has sometimes been characterized as a public sector application of the feasibility studies a prudent private investor would make prior to committing capital. This view is misleading. BC analysis is directly addressed to decision making at a governmental level. Unlike a voluntary private investment, the subject of BC evaluation may encompass conflicting individual interests and unpriced goods and services. As an extramarket activity, BC analysis applies a particular set of utilitarian principles to determine whether or not a regulatory action is desirable.

Economic analysis distinguishes two fundamental dimensions of economic or regulatory policy: (1) an efficiency dimension concerned with the avoidance of economic waste and (2) a distributional dimension concerned with the share of output across sets or classes of individuals. In an idealized economy where property rights are well-defined and markets are complete, self-seeking, voluntary exchange eliminates economic waste by searching out potential gains from trade. The incremental process of exchange leads to an allocation of goods and services that is Pareto efficient: it is not possible to make any individual better off without making some other individual worse off. If the economy is Pareto efficient and no one can be made better off without making someone worse off, any regulatory change bestows benefits on one set of individuals only by imposing harm on some other set of individuals. Therefore, in a Pareto efficient economy, regulatory policy can at best accomplish a distributional objective.

In practice, economic exchange is less than ideal and valued goods and services may unnecessarily be forgone. Property rights are often ill-defined and, particularly in the case of environmental goods, consumption is often nonrival. In these cases, the mere costs of exchange may exclude the possibility of beneficial trade.[1] Where such impediments to exchange occur, regulatory action may offer the possibility of an efficiency gain. By redefinition of entitlements or by direct provision, regulatory action may overcome an impediment to exchange and result in benefits that exceed the costs.

The mere presence of impediments to trade, however, does not guarantee the net benefits of regulatory action. Of the feasible set, relatively few of the possible regulatory actions are likely to circumvent impediments to trade and satisfy an efficiency goal of benefits in excess of project costs. Arbitrary regulatory action is likely to simply redistribute extant benefits and costs. In addition, interest groups are always present to urge the selection of self-serving redistributive policies (Rausser, Peltzman, Navarro). Such rent-seeking initiatives are likely to ignore the potential for overall efficiency gains. To sort out the efficiency and distributional impacts of policy, regulatory analysis requires reliable methods of assessment.

Benefit cost analysis is one such method. As a search for efficiency gains, BC analysis applies the potential Pareto improvement test. A regulatory policy is potential Pareto improvement if the benefits to those who gain from a policy action are sufficient to compensate those who are harmed by regulatory change. Thus, if an appropriate measure of benefits exceeds costs, policy action is a potential Pareto improvement and it is conceivable, via compensation, to make at least one set individuals better off without making other parties worse off. Such a policy is a potential efficiency gain.

Without compensation, policy action fails to meet the Pareto improvement criterion. Without compensation, a typical policy benefits one group of individuals at the expense of another and specific welfare or ethical judgements are necessary to weigh the losses of one set of individuals against the gains of another. Not surprisingly, the choice of an appropriate or acceptable set of ethical tradeoffs sustains continuing academic and political debate. Nevertheless, such welfare tradeoffs and concomitant distributional impacts are a primary concern of the regulatory process (Zeckhauser). In this context, BC information provides essential quantitative data on the distribution of gains and losses.

Measuring Benefits and Costs

At the core of benefit cost analysis are the gains and losses experienced by individuals. Since these gains and losses may be incurred across a range of goods and services, BC analysis attempts to translate diverse policy impacts into a common money metric. Because the analysis seeks to determine the extent to which individuals are made better off or worse off by the impacts of policy, an informative money metric is linked to the utility levels attainable under either the initial or post policy situations.

The development of a metric associated with market price changes begins with Marshall's concept of consumer's surplus, the excess that a consumer "would be willing to pay rather than go without the thing" [Marshall, p. 124].[2] The Marshallian measure is directly linked to the ordinary notion of demand and offers an intuitively appealing metric of price change. Moreover, as shown by Hotelling, it can be extended to the context of multiple price changes. Unfortunately, as shown by Hicks [1956], the Marshallian consumer's surplus measure cannot be consistently linked to either the initial or post policy level of well-being.

In order to link the evaluation metric to utility, Hicks [1941, 1943, 1956] reformulated the Marshallian analysis in an ordinal framework of preferences and indifference surfaces. The reformulation identified two measures of benefit or cost: a compensating measure and an equivalent measure. The Hicksian compensating measure (HC) was referenced to an individual's initial utility level. HC was defined as the minimum amount of income compensation required in order to leave an individual at the initial utility level when faced with the post change set of prices. An individual would be indifferent between the initial situation and a compensated post change situation. The Hicksian equivalent measure (HE) was referenced to the uncompensated, post change utility level. HE was defined as the amount of income paid or received that would leave the individual at the post change level of utility when faced with the initial set of prices. HE would impose a utility gain or loss equivalent to the price change. By definition, HC and HE were directly and clearly linked to the utility levels associated with a price change.

The Hicksian analysis demonstrated that HC and HE are generally different in magnitude. Additionally, Hicks showed that the Marshallian measure of consumer's surplus falls between HC and HE. Hicks argued that these differences between alternative benefit measures would usually be rather trivial, "a fiddling business" [Hicks (1941)]. Nevertheless, for goods which are income elastic and/or account for a substantial share of an individual's budget--that is, goods which are highly valued, and in the extreme, essential--the differences between HC and HE are empirically important.

Much research has been directed toward characterizing the conceptual and empirical properties of the Hicksian and Marshallian measures. Willig [1976, 1979] analyzed both single and multiple price changes and developed formulae to approximate the empirical differences between consumer's surplus, HC, and HE. Chipman and Moore showed that HE is a generally consistent measure of individual utility. Mishan (1960) and Brookshire, Randall, and Stoll demonstrated that HC, as a measure of compensation, is generally consistent with the potential Pareto improvement test and, therefore, with an underlying rationale of BC analysis.

Regulatory impacts are not restricted to price impacts and recent efforts have extended the Hicksian measures to the quality and quantity dimensions of policy change. Mäler was perhaps first to offer a comprehensive analysis of the Hicksian measures in a quality or quantity context. Randall and Stoll (1980a, 1980b) defined the conditions under which market prices fail to be precise value indicators and adapted Willig's analysis of the Hicksian measures to the case of parametric quality and quantity changes. Just, Hueth, and Schmitz detailed the linkage between the Willig and Randall and Stoll (1980a) results. Small and Rosen and, more recently, Hanemann extended the analysis of quality change to a quantal choice framework. Finally, Brookshire, Randall, and Stoll defined the relationship between the Hicksian measures and the common language concepts of value such a willingness to pay and willingness to accept compensation.

The Analytical Structure of Benefits and Costs

The envelope theorem establishes the existence of a set of potential functions that entirely summarize the optimizing behavior of individuals

[Silverberg (1984)]. An indirect utility function states the maximum utility attainable given prices, qualities, and income. An expenditure function states the minimum income required to attain a given level of utility at given prices and qualities. By using the duality relationship between the minimum expenditure to satisfy a utility constraint and the maximum utility given a budget constraint, the Marshallian and Hicksian measures can be stated in tractible analytical forms that fully embody the restrictions imposed by preferences, constrained budgets, and optimization.

The envelope function framework has led to numerous extensions and clarifications in the analysis of both the Marshallian and Hicksian measures. For instance, multiple price changes and the uniqueness of the Marshallian measure have been the subject of debate ever since Hotelling introduced the issue and an approximate solution in 1938. With the advent of HC and HE, the debate has included the Hicksian measures as well. However, in the envelope function context, it is readily shown that both HC and HE are path independent of any intermediate set of price changes and that the initial and final set of prices uniquely determine the size of both HC and HE. Using analogous analytical techniques, the Marshallian measure is shown to be path dependent and therefore not unique [Silberberg (1978)]. The envelope function approach can also be used to detail the welfare properties of HC and HE [Chipman and Moore] and to clarify empirical relationships between the Hicksian and Marshallian BC measures [Hausman; Bergland and Randall]. Finally, the structural restrictions implied by the envelope functions have been shown the be central to the derivation of a valid benefit cost design [Hoehn and Randall; Hoehn].

Benefit Cost Design and Current Research

Regulatory change imposes a broad range of impacts on individual's within an economy. A national regulatory initiative may directly affect (1) the environmental opportunities open to individuals, (2) the prices of market goods and services, and (3) the profitability of firms in which individuals are stockholders and wage earners. Thus, the overall impact of a regulatory policy is multidimensional. When the multiple policies of a number of governmental agencies are considered, the impact is that much more complex. Conventional benefit cost design tends to ignore the complex and compound effects of such multipart policies. The conventional approach partitions complex initiatives into their component parts and evaluates each component on a piecemeal basis. Sources of interaction and substitution--of complementarity and competitiveness--are ignored [cf, Fraas]. Given only what is known about the evaluation of multiple price changes [Hotelling; Willig (1979)], the conventional approach is certain to result in error.

Several recent studies suggest that the error in conventional BC outcomes may be significant even when applied to fairly limited sets of policy impacts. Braetigam and Noll evaluate the welfare impact of surface freight tariff regulation using the results of both (1) a conventional design and (2) Hotelling's approximately valid approach to multiple price changes.[3] Results suggest that the conventional approach misstates the net welfare impact of policy by three to four hundred percent.

Though designs appropriate to multiple price changes are not new, economists have only recently taken up the problem of multiple changes in parametric qualities or quantities. To address this problem, Lave derives an evaluation design from a social welfare maximization framework. Lave argues that the structure of regulatory institutions encourages agencies to ignore policy "contradictions" [Lave, p. 124] and shows that a valid evaluation design requires a simultaneous consideration of all policy impacts. To demonstrate the feasibility of a valid design, Lave analyzes a regulatory case involving the tradeoffs between automobile fuel consumption and passenger safety. Empirical results for a conventional design are not given.

Hoehn and Randall (HR) approach the problem of evaluation design from a somewhat different perspective.[4] First, HR use the envelope function structure to derive a valid evaluation design directly from the definition of a Hicksian compensating measure. Since it is based on HC, the derived evaluation design is entirely consistent with the potential Pareto improvement objective of BC evaluation. Second, HR show that two basic BC approaches satisfy the restrictions of a valid design: a simultaneous approach similar to Lave's and a sequenced approach. Third, HR demonstrate that the error resulting from conventional benefit cost design is systematic and tends to overstate the benefits of policy change for an empirically important subset of cases. To test this bias empirically, HR apply both the valid and conventional designs to an empirical case involving air quality. The conventional design is shown to overstate a valid total benefit measure by approximately thirty-five percent and specific component measures by more than four hundred percent.

Research Objectives

The initial results reported in Hoehn and Randall provide a foundation for the development of reliable benefit cost designs. The envelope function approach taken by HR is not only general and tractible at an analytical level but also underlies the estimation techniques commonly used in BC analysis.

The primary objective of the current report is to extend and generalize the initial results of HR in order to work toward improved, routine BC designs. To guide the extension of the HR results, five specific objectives were outlined at the outset of this study. These objectives are reported and discussed below.

Objective 1. To complete the theoretical analysis of the conditions in which competitive and complementary effects can be expected to be significant in the routine BC evaluation of public policy.

Initial research indicates that a commonly used utility structure, the additively separable form, implies general competitive effects between the quality and quantity impacts of policy [Hoehn and Randall]. The problem then is to link the concept of additive separability to identifiable choice contexts. For example, imperfect information and uncertainty may introduce a degree of additive separability through the expected utility property. Thus, if the use or impact of policy components is uncertain, it may be that the expected utility property is sufficient to induce additive separability and consequent competitive effects between sets of policy components. Such effects remain to be investigated.

Objective 2. To explore apparent asymmetries in the valuation of regulatory programs to augment or reduce the level of quality and quantity amenities.

An important distinction in the literature on valuation and benefit cost analysis is that between willingness to pay (WTP) and willingness to accept compensation (WTA). Viewed in terms of compensating variation, WTP measures the benefit and WTA measures the cost of a regulatory program. The benefits of a regulatory change outweigh the costs if WTP - WTA > 0.

The initial BC evaluation framework [Hoehn and Randall, 1982] underscores the distinction between the HC measures of WTA and WTP. For instance, if general competition exists between policy components, the conventional measure of willingness to pay (wtp) overstates the conceptually valid measure of WTP. For WTA, however, just the opposite effect occurs. For WTA, competition implies that the conventional measure of willingness to accept (wta) understates the valid measure, WTA. Therefore, if competition is the general rule,

$$wtp - wta > WTP - WTA.$$

That is, if competition is the general rule, the conventional approach tends to overstate the desirability of policy change.

Initial results indicate that competition may be routine. Additively separable utility, perhaps induced by the expected utility property, certainly leads to competitive effects. More generally, limited individual budgets appear to introduce an analogous competitive effect for wtp but have, at the outset of this study, not yet been investigated for the case of wta.

Objective 3. To complete the ongoing analysis to generalize the necessary and sufficient conditions for valid cross-component aggregation and disaggregation of program benefits.

Restrictions imposed by the line integral concept [Apostol] provide one set of sufficient conditions for a valid evaluation of multipart policies. Though not yet fully investigated, initial research indicates that in cases involving either competitive or complementary effects, the restrictions imposed by the line integral concept are necessary for valid aggregation. As a first step in the proposed research, the necessary and sufficient conditions for valid evaluation will be verified.

Objective 4. To work toward operational and valid benefit cost designs that are appropriate to the constraints and requirements of typical benefit cost methods and contexts.

Viewed as a Taylor series expansion, conventional BC design allows the estimation of a valid valuation up to a second order approximation--but without taking account of the cross-component effects that are apparently crucial to a valid outcome. To replace the flawed approximation implied by the conventional design, two exact valuation approaches have been developed. The first applies to a set of component valuations elicited through contingent valuation. The second fits a system of demand-based valuations obtained through weak complementarity relations.[5] While these exact designs are satisfactory as conceptual guides, they are not yet in a form that specifies the categories of data required for actual estimation and valuation.

To accomplish Objective 4, the analysis will work toward estimable specifications of the exact valuation designs developed for contingent and demand based valuation. Though perhaps outside the reach of the current proposal, a long range goal of the specification and approximation efforts is to develop field-operational rules of thumb to approximate a correct valuation using the information obtained in a conventional procedure.

Objective 5. To describe the conditions under which the conventional design, the valid evaluation structure, and the approximate procedures may be optimal, satisfactory, or unreliable as indicators of benefits and costs.

The investigation outlined by the above four objectives works toward the development of a set of theoretically well-characterized, applied designs for the BC evaluation of complex regulatory programs. Specifically, Objective 4 advances toward a specification of the empirical designs while Objectives 1, 2, and 3 aid in characterizing the applied designs in terms of the substitution relations which they allow, the asymmetries which may arise, and the degree to which the designs conform to the generally valid aggregation conditions.

Criteria will be developed to summarize the overall characteristics of different BC designs. One candidate set of criteria would define optimal and satisfactory BC indicators in terms of the potential Pareto improvement objective that is fundamental to BC analysis.

An Outline of the Research Report

The report is organized to around the Objectives outlined in the previous section. Chapters II and III address Objectives 1, 2, and 3. In Chapter I the basic structure of a valid BC framework is developed using (1) the definition of a Hicksian BC measure and (2) the analytical structure of the indirect utility and expenditure functions. The basic design is then used to describe two valid but operationally different approaches to BC analysis. To characterize the error in conventional procedures, conventional and valid BC outcomes are qualitatively compared. Conventional procedures are shown to ignore substitution interactions among policy components. As a result, conventional benefit cost outcomes are likely to routinely introduce error into BC outcomes. The analysis of Chapter II, however, leaves open the possibility that the error induced by conventional procedures might cancel or average out as the number of evaluated components becomes large.

Chapter III investigates the possibility that the conventional design might approximate a valid benefit cost outcome as the number of evaluated components becomes large. An initial result, however, demonstrates that the error in conventional procedures accumulates and becomes systematic as the number of components grows. Conventional benefit cost outcomes are shown to systematically overstate the net benefits of policy change. To examine whether conventional procedures actually misstate the sign of benefit cost outcomes, a further specification of the economy is outlined. With this extended specification, the valid benefit cost design is expanded to include price changes, parametric qualities and quantities, and the profits of regulated firms. Once again, conventional procedures are shown to systematically overstate the net benefits associated with policy change. Moreover, if the marginal costs of policy change are assumed to positive, conventional procedures are shown to misidentify net loss policies as potential Pareto improvements.

Chapter IV works toward the specification of operational approximations of the valid BC design (Objective 4). First, the key structural elements of the valid design are illustrated in a Cobb-Douglas framework. Second, a Taylor series approximation (TSA) is used to derive a full range of alternative approximations to the valid design. To demonstrate the flexibility of the

TSA approach, the valid design is implemented on simulated benefits and costs. Results indicate the impact of substitution on BC outcomes.

Chapter V summarizes the research findings and discusses the properties of (1) the conventional design, (2) the exact and valid approaches, and (3) the approximate procedures.

Endnotes

1. For a full discussion, see Randall [1982].

2. Writing somewhat before Marshall, Dupuit introduced a concept similar to the Marshallian measure. Dupuit's work, however, seems to have been overlooked until the mid-twentieth century.

3. The Hotelling approach is approximate in the sense that it addresses welfare change but uses the Marshallian demands.

4. Initial findings regarding a valid evaluation design also appear in Randall, Hoehn, and Tolley.

5. The use of weak complementarity in BC evaluation is discussed in Mäler.

Chapter II

CONVENTIONAL AND VALID BENEFIT COST DESIGNS

Regulatory change alters the institutional and physical environment of individuals and firms. Some of these environmental impacts may directly affect the well-being of individuals. Other impacts shift the cost structure of firms. Shifts in either supply or demand lead to changes in market prices. These complex and interrelated impacts pose severe problems of prediction and evaluation for benefit cost analysis. The solution of conventional procedures, however, is somewhat too simple: Policy interactions tend to be ignored and impacts are evaluated independently. Recent case studies confirm intuition and indicate that conventional procedures result in substantial error [Braeutigam and Noll; Hoehn and Randall].

The objective of this Chapter is to specify an analytical framework to guide improvements in benefit cost design. To identify the basic structure of benefits and costs, the Hicksian compensating (HC) measure is defined within an envelope function framework.[1] The envelope function approach enables the BC framework to encompass both the direct utility impacts of environmental change as well as the impacts sustained through market price effects. The HC concept ensures that BC outcomes are consistent with the potential Pareto improvement form of BC analysis [Mishan; Brookshire, Randall, and Stoll].

The derived BC framework extends the structural restrictions noticed by Hotelling to the general problem of evaluating an arbitrary set of price and environmental changes. The valid benefit cost (VBC) design suggests two different evaluation strategies: (1) an overall, single-step valuation similar in structure to Lave's welfare maximization approach and (2) a sequenced, component by component approach. A structural comparison of both the conventional and VBC designs demonstrates that the conventional approach ignores the restrictions of the VBC design. An initial qualitative comparison of BC outcomes generalizes the empirical results of recent case studies: the conventional design is almost certain to result in erroneous BC outcomes.

Regulatory Change and the Hicksian Benefit Measures

This section constructs the analytical tools that are used to specify both the conventional and valid BC designs. The section begins with a description of the economy and the role of regulatory policy.[2] The impacts of policy are summarized in terms of environmental and price effects. Given a set of market prices, environmental quality levels, and endowments, the indirect utility and expenditure functions are derived. These envelope functions are then used to define the net benefits associated with single impact policies.

The economy is composed of individual households, firms, and a regulatory agency or agencies. Individual households are endowed with a set of resources (e.g., labor) that are exchanged at market prices. Households gain utility from both market goods and environmental amenities.[3] Firms transform market goods inputs into both market goods and environmental outputs.[4] The environmental output of each firm contributes to an ambient level of environmental quality. The production possibilities of any particular firm are not affected by the production levels of other firms. Only individuals are directly impacted by the ambient level of environmental parameters.

Both individuals and firms behave atomistically and take both market prices and ambient environmental parameters as given. Thus, the role of regulatory agencies is to control the environmental outputs of firms in order to achieve a given level of ambient environmental quality. Such controls affect both ambient environmental quality as well as the cost structure of firms. Consequent shifts in both demand and supply lead to changes in market prices, profits, and rental incomes.

In order to simplify the analysis and focus on the fundamental restrictions of a VBC design, a full consideration of firm the level effects of regulatory policy is delayed until Chapter III. For the purpose of this Chapter, it is assumed that the entry and exit of firms leaves aggregate profits at zero both before and after a regulatory change. With zero economic profits, regulatory impacts are fully summarized by the changes in prices and environmental parameters as these impact on the opportunity sets of individual households.

Given the economic structure, the analytical description of regulatory outcomes can be specified in terms of a vector of market price and environmental impacts. Market prices are represented by a vector $\mathbf{p} \in \mathbf{R}^J$. Prices are normalized by letting x_1 be the numeraire and $p_j = (p_j/p_1)$ for all $j \in \{1,\ldots,J\}$. Environmental parameters are a vector $\mathbf{q} \in \mathbf{R}^K$. The initial policy situation is

$$(2.1) \qquad (\mathbf{p}^0,\mathbf{q}^0) = (p_1^0,\ldots,p_J^0,q_1^0,\ldots,q_K^0).$$

For an single impact policy that changes environmental element q_k from q_k^0 to q_k^1, the initial policy situation is, of course, $(\mathbf{p}^0,\mathbf{q}^0)$. The post change situation includes both the environmental impacts as well as a set of consequent price impacts. The postpolicy or post change situation is denoted

$$(2.2) \qquad (\mathbf{p}_k^1,\mathbf{q}_k^1) = (p_1^1,\ldots,p_J^1,q_1^0,\ldots,q_{k-1}^0,q_k^1,q_{k+1}^0,\ldots,q_K^0)$$

where $\mathbf{p}_k^1$ is a vector of equilibrium prices[5] subsequent to the change from $\mathbf{q}_k^0$ to $\mathbf{q}_k^1$.

The impact of a <u>multipart</u> policy that shifts environmental parameters from $\mathbf{q}^0$ to

$$(2.3) \qquad \mathbf{q}^G = (q_1^1,\ldots,q_G^1,q_{G+1}^0,\ldots,q_K^0)$$

is denoted by the post change situation $(\mathbf{p}^G,\mathbf{q}^G)$ where $\mathbf{p}^G$ is a vector of equilibrium prices subsequent to the multipart change from $\mathbf{q}^0$ to $\mathbf{q}^G$. A multipart policy, $\mathbf{q}^G$, changes environmental parameters q_1 through q_G but leaves environmental parameters q_{G+1} through q_K unaffected.

In the discussion below, it is also useful to represent a multipart policy as a sequence of changes. For instance, the multipart policy $\mathbf{q}^G$ could be represented as a two step sequence of impacts by changing $(\mathbf{p}^0,\mathbf{q}^0)$ to $(\mathbf{p}^k,\mathbf{q}^k)$ first,

$$(2.4) \qquad \mathbf{q}^k = (q_1^1,\ldots,q_k^1,q_{k+1}^0,\ldots,q_K^0),$$

and then shifting $(\mathbf{p}^k,\mathbf{q}^k)$ to $(\mathbf{p}^G,\mathbf{q}^G)$. Note that unlike a single impact policy, $\mathbf{q}_k^1$, which changes only q_k, a multipart policy $\mathbf{q}^k$ affects environmental parameters q_1 through q_k and leaves only q_{k+1} through q_K unaffected.

A household $i \in \{1,\ldots,I\}$ derives utility from environmental parameters, $\mathbf{q}$, and market goods, $\mathbf{x}_i$, where the subscript i denotes the market goods vector consumed by household i. Each household i is endowed with resources $\bar{\mathbf{x}}_i \geq \mathbf{0}$, $\bar{\mathbf{x}}_i \in \mathbf{R}^J$ where $\bar{x}_{ij} > 0$ for some $j \in \{1,\ldots,J\}$. Across all households, the aggregate resource endowment is $\bar{\mathbf{x}} = \sum_{i=1}^{I} \bar{\mathbf{x}}_i$.

Households combine market goods and environmental parameters to produce well-being or utility. The utility possibilities of household i are summarized by a utility function, $u_i = u_i(\mathbf{x}_i,\mathbf{q})$, that is strictly increasing, continuous, and strictly quasiconcave. Given environmental parameters, $\mathbf{q}$, and income, $\mathbf{p}\bar{\mathbf{x}}_i$, a household selects a consumption bundle, $\mathbf{x}_i$, that maximizes utility. A household's indirect utility function, $v_i(\mathbf{p},\mathbf{q},m_i)$, states the maximum utility attainable at given prices, environmental parameters, and income, m_i,

$$(2.5) \qquad v_i(\mathbf{p},\mathbf{q},m_i) = \{u_i \mid u_i = \max_{\mathbf{x}_i} u_i(\mathbf{x}_i,\mathbf{q}) \text{ s.t. } \mathbf{p}\mathbf{x}_i = \mathbf{p}\bar{\mathbf{x}}_i,\ m_i = \mathbf{p}\bar{\mathbf{x}}_i\}.$$

By Roy's identity [Varian (1978)], market goods demands are a function of prices, income, and environmental parameters.

The household's expenditure function states the minimum expenditure on market goods required to attain utility level u_i as a function of market prices and environmental parameters,

$$(2.6) \qquad e_i(\mathbf{p},\mathbf{q},u_i) = \{e_i \mid e_i = \min_{\mathbf{x}_i} \mathbf{p}\mathbf{x}_i \text{ s.t. } u_i \leq u(\mathbf{x}_i,\mathbf{q})\}$$

The defined expenditure function is strictly increasing, homogeneous of degree 1, strictly concave, and continuous in $\mathbf{p}$. In $\mathbf{q}$, the expenditure function is strictly decreasing and strictly convex [Hoehn].

The Hicksian compensated demands state the consumption bundle that sustains u_i with a minimum expenditure, $e_i(\mathbf{p},\mathbf{q},u_i)$. By Hotelling's lemma [Varian (1978)], the Hicksian demands are $\mathbf{x}_i^*(\mathbf{p},\mathbf{q},u_i) = \mathbf{Dp}\_e_i(\mathbf{p},\mathbf{q},u_i)$ and $\mathbf{p}\mathbf{x}_i^* = e_i(\mathbf{p},\mathbf{q},u_i)$.[6]

At the initial situation, $(\mathbf{p}^0,\mathbf{q}^0)$, an individual household requires a minimum expenditure of $e_i^0 = e_i(\mathbf{p}^0,\mathbf{q}^0,u_i^0)$ in order to attain an initial level of utility $u_i^0 = v_i(\mathbf{p}^0,\mathbf{q}^0,m_i^0)$.

A utility allocation is a set, $\tilde{\mathbf{u}} = \{u_1,\ldots,u_I\}$, that specifies the utility attained by each household. At market prices $\mathbf{p}$ and environmental levels $\mathbf{q}$, the minimum aggregate expenditure required to maintain the utility allocation $\tilde{\mathbf{u}}$ is simply the sum of the minimum household expenditures required to maintain $u_i \in \tilde{\mathbf{u}}$,

$$(2.7) \qquad e(\mathbf{p},\mathbf{q},\tilde{\mathbf{u}}) = \sum_{i=1}^{I} e_i(\mathbf{p},\mathbf{q},u_i), \quad u_i \in \tilde{\mathbf{u}}.$$

The aggregate consumption bundle sufficient to maintain $\tilde{\mathbf{u}}$ at prices, $\mathbf{p}$, and environmental parameters, $\mathbf{q}$, is

$$(2.8) \qquad \mathbf{x}(\mathbf{p},\mathbf{q},\tilde{\mathbf{u}}) = \mathbf{Dp\_e}(\mathbf{p},\mathbf{q},\tilde{\mathbf{u}})$$

$$= \sum_{i=1}^{I} \mathbf{Dp\_e}_i(\mathbf{p},\mathbf{q},u_i)$$

$$= \sum_{i=1}^{I} \mathbf{x}_i(\mathbf{p},\mathbf{q},u_i)$$

where $\tilde{\mathbf{u}} = \{u_1,\ldots,u_I\}$. Finally, $\mathbf{px}(\mathbf{p},\mathbf{q},\tilde{\mathbf{u}}) = e(\mathbf{p},\mathbf{q},\tilde{\mathbf{u}})$.

With both the indirect utility and expenditure functions defined, the Hicksian benefit measures can be stated in a tractible analytical framework. By definition, the HC measure for a given policy change is the amount of income, paid or received, that would leave an individual household at the initial level of utility, $u_i^0 = v_i(\mathbf{p}^0,\mathbf{q}^0,m_i)$, at the <u>post</u> change level of prices and environmental parameters, $(\mathbf{p}_k^1,\mathbf{q}_k^1)$ [cf., Hicks (1943, 1956); Mishan (1971); Brookshire, Randall and Stoll]. Letting compensation paid by the individual be positive and compensation paid to the individual be negative, Definition 2.1 states the HC measure attributable to a single impact policy.

Definition 2.1. Let the initial situation be $(\mathbf{p}^0,\mathbf{q}^0)$, let $\mathbf{q}_k^1 = (q_1^0,\ldots,q_k^1,\ldots,q_K^0)$ be a single impact policy under consideration, and let $\mathbf{p}_k^1$ be prices subsequent to the change from $(\mathbf{p}^0,\mathbf{q}^0)$ to $\mathbf{q}_k^1$. The post change situation is therefore $(\mathbf{p}_k^1,\mathbf{q}_k^1)$ and the post change level of income is $m_i^1 = \mathbf{p}_k^1\bar{\mathbf{x}}_i$. Given the initial utility level $u_i^0 = v_i(\mathbf{p}^0,\mathbf{q}^0,m_i^0)$, the Hicksian compensating measure is

(2.9.1) $$hc_i(\mathbf{q}_k^1,\mathbf{q}^0) = \mathbf{p}_k^1\bar{\mathbf{x}}_i - e_i(\mathbf{p}_k^1,\mathbf{q}_k^1,u_i^0)$$

(2.9.2) $$= (\mathbf{p}_k^1 - \mathbf{p}^0)\bar{\mathbf{x}}_i + e_i(\mathbf{p}^0,\mathbf{q}^0,u_i^0) - e_i(\mathbf{p}_k^1,\mathbf{q}_k^1,u_i^0)$$

(2.9.3) $$= \int_{\mathbf{p}^0}^{\mathbf{p}_k^1} \bar{\mathbf{x}}_i d\mathbf{p} - \int_{\mathbf{z}^0}^{\mathbf{z}_k^1} D\mathbf{z}\_e_i(\mathbf{p},\mathbf{q},u_i^0)d\mathbf{z}$$

where $\mathbf{z} = (\mathbf{p},\mathbf{q})$ and the integrals are line integrals. Summing over all individuals, the total Hicksian compensating measure is

(2.10.1) $$hc(\mathbf{q}_k^1,\mathbf{q}^0) = \mathbf{p}_k^1\bar{\mathbf{x}} - e(\mathbf{p}_k^1,\mathbf{q}_k^1,\tilde{\mathbf{u}}^0)$$

(2.10.2) $$= (\mathbf{p}_k^1 - \mathbf{p}^0)\bar{\mathbf{x}} + e(\mathbf{p}^0,\mathbf{q}^0,\tilde{\mathbf{u}}) - e(\mathbf{p}_k^1,\mathbf{q}_k^1,\tilde{\mathbf{u}}^0)$$

$$(2.10.3) \qquad = \int_{\mathbf{p}^0}^{\mathbf{p}_k^1} \bar{\mathbf{x}}d\mathbf{p} - \int_{\mathbf{z}^0}^{\mathbf{z}_k^1} \mathbf{D}z\_e(\mathbf{p},\mathbf{q},\tilde{\mathbf{u}}^0)d\mathbf{z}$$

where $\tilde{\mathbf{u}}^0 = \{u_1^0,\ldots,u_I^0\}$.

Definition 2.1 states several different but equivalent forms of HC. Line (2.9.1) states that the HC measure for household i can be measured as the difference between the post change level of income and the minimum level of expenditure that sustains u_i^0 at post change prices and environmental parameters. Line (2.9.2) states that HC can be viewed as the change in income or resource rents minus the change in minimum expenditure required to sustain u_i^0. Line (2.9.3) states HC as the integral over a set of marginal valuations. Finally, lines (2.10.1) through (2.10.3) give analogous forms of the total HC measure obtained by summing across all individuals, $i \in \{1,\ldots,I\}$.

As described by Definition 2.1, HC encompasses the full impact of a single impact policy. The resulting net benefit measure is consistent with the potential Pareto improvement form of BC analysis. If $hc(\mathbf{q}_k^1,\mathbf{q}^0) > 0$, the single impact change is a potential Pareto improvement. If $hc(\mathbf{q}_k^1,\mathbf{q}^0) < 0$, the change fails the potential Pareto improvement test.

Conventional and Valid Benefit Cost Designs

In this section the analytical structure developed above is used to derive both the conventional and correct BC designs. The conventional design begins with the HC measure defined for each of the component impacts. The valid design begins with the conceptually valid HC measure defined across the overall impact of a multipart policy. Because the conventional approach ignores the interactions that arise across the multiple impacts of policy, conventional and valid BC outcomes are likely to diverge.

Before proceeding, a definition of terms is important. In analyzing the Hicksian measures, two types of total valuations can be distinguished: (1) a valuation that is the sum total of the household specific valuations, hc_i, $i \in \{1,...,I\}$, and (2) a valuation that encompasses the overall or aggregate effect of a multipart policy. To distinguish the two valuations, the first will be referred to as a total valuation. The second is referred to as an aggregate or overall valuation of policy.

The conventional approach to BC analysis is one of independent valuation and summation (IVS). With IVS, the component impacts of policy are valued independently as if each impact were an isolated policy. Where an overall evaluation is of interest, the independent valuations are simply added up. Thus, the essential structural feature of IVS is the single impact benefit measure described by Definition 2.1. Definition 2.2 describes the analytical form of the conventional approach.

Definition 2.2. Let policy be defined as a G element set of environmental changes from $\mathbf{q}^0$ to $\mathbf{q}^G = (q_1^1,...,q_k^1,...,q_G^1,q_{G+1}^0,...,q_K^0)$. Let the vector $\mathbf{p}_k^1$ be the set of market prices subsequent to the independently considered change from $\mathbf{q}^0$ to $\mathbf{q}_k^1 = (q_1^0,...,q_{k-1}^0,q_k^1,q_{k+1}^0,...,q_K^0)$. The the total valuation given by independent valuation and simple summation (IVS) is

$$(2.11) \qquad ivs_i(\mathbf{q}^G,\mathbf{q}^0) = \sum_{k=1}^{G} hc_i(\mathbf{q}_k^1,\mathbf{q}^0)$$

for a household i and the aggregate valuation is

$$(2.12.1)\quad \mathrm{ivs}(\mathbf{q}^G,\mathbf{q}^0) = \sum_{k=1}^{G} \mathrm{hc}(\mathbf{q}_k^1,\mathbf{q}^0)$$

$$(2.12.2)\quad = \sum_{i=1}^{I} \mathrm{ivs}_i(\mathbf{q}^G,\mathbf{q}^0)$$

across all households $i \in \{1,\ldots,I\}$.

Guided by the benefit outcomes of a conventional design, the change from $\mathbf{q}^0$ to $\mathbf{q}^G$ would be viewed as a potential Pareto improvement if $\mathrm{ivs}(\mathbf{q}^G,\mathbf{q}^0) > 0$. The change would fail the potential Pareto improvement test if $\mathrm{ivs}(\mathbf{q}^G,\mathbf{q}^0) < 0$.

The structure of the conventional design becomes clear when each component valuation is written out in full. For the aggregate IVS valuation, this structure is

$$(2.13.1)\quad \mathrm{ivs}(\mathbf{q}^G,\mathbf{q}^0) = \sum_{k=1}^{G} \mathrm{hc}(\mathbf{q}_k^1,\mathbf{q}^0)$$

$$(2.13.2)\quad = \mathbf{p}_1^1\bar{\mathbf{x}} - e(\mathbf{p}_1^1,\mathbf{q}_1^1,\mathfrak{U}^0) + \ldots$$

$$(2.13.3)\quad + \mathbf{p}_k^1\bar{\mathbf{x}} - e(\mathbf{p}_k^1,\mathbf{q}_k^1,\mathfrak{U}^0) + \ldots$$

$$(2.13.4)\quad + \mathbf{p}_G^1\bar{\mathbf{x}} - e(\mathbf{p}_G^1,\mathbf{q}_G^1,\mathfrak{U}^0).$$

In line (2.13.2), the impact $\mathbf{q}_1^1$ is evaluated as if it were an isolated, unique change from the initial situation, $(\mathbf{p}^0,\mathbf{q}^0)$. In lines (2.13.3) and (2.13.4), the changes to $\mathbf{q}_k^1$ and $\mathbf{q}_G^1$ are also evaluated as if each were an isolated, unique change to $(\mathbf{p}^0,\mathbf{q}^0)$. The IVS approach values each of the G impacts as if it were an isolated, incremental change from the initial policy situation, $(\mathbf{p}^0,\mathbf{q}^0)$. The approach fails to account for the overall or aggregate impact of the G impact change.

The problem now is to develop a conceptually valid BC design that accounts for both the overall impact of policy and the structural interactions among policy components. The approach taken here is to return to the basic definition of the Hicksian compensating measure and to define the aggregate net benefit of a multipart policy in a manner analogous to Definition 2.1. That is, the Hicksian compensating measure for a multipart policy is the amount of income, paid or received, that would leave an individual at the initial level of utility at the post change level of prices and environmental parameters. Definition 2.3 states the HC for a multipart policy in analytical form.

Definition 2.3. Let the initial situation be $(\mathbf{p}^0,\mathbf{q}^0)$, let $\mathbf{q}^G = (q_1^1,\ldots,q_G^1,q_{G+1}^0,\ldots,q_K^0)$ be a G impact multipart policy, and let $\mathbf{p}^G$ be the unique vector of market price changes induced by the change from q^0 to $\mathbf{q}^G$. Given an initial utility level of $u_i^0 = v_i(\mathbf{p}^0,\mathbf{q}^0,u_i^0)$, the Hicksian compensating measure of net benefits attributable to the multipart policy is

$$\text{(2.14.1)} \quad hc_i(\mathbf{q}^G,\mathbf{q}^0) = \mathbf{p}^G\bar{\mathbf{x}}_i - e_i(\mathbf{p}^G,\mathbf{q}^G,u_i^0)$$

$$\text{(2.14.2)} \quad = (\mathbf{p}^G - \mathbf{p}^0)\bar{\mathbf{x}}_i + e_i(\mathbf{p}^0,\mathbf{q}^0,u_i^0) - e_i(\mathbf{p}^G,\mathbf{q}^G,u_i^0)$$

$$\text{(2.14.3)} \quad = \int_{\mathbf{p}^0}^{\mathbf{p}^G} \bar{\mathbf{x}}_i\,d\mathbf{p} - \int_{\mathbf{z}^0}^{\mathbf{z}^G} \mathbf{Dz\_}e_i(\mathbf{p},\mathbf{q},u_i^0)\,d\mathbf{z}$$

where $\mathbf{z} = (\mathbf{p},\mathbf{q})$ and the integrals are line integrals. Summing over all individuals, the total Hicksian compensating measure is

$$(2.15.1)\quad hc(\mathbf{q}^G,\mathbf{q}^0) = \mathbf{p}^G\bar{\mathbf{x}} - e(\mathbf{p}^G,\mathbf{q}^G,\mathbf{\tilde{u}}^0)$$

$$(2.15.2)\quad = (\mathbf{p}^G - \mathbf{p}^0)\bar{\mathbf{x}} + e(\mathbf{p}^0,\mathbf{q}^0,\mathbf{\tilde{u}}) - e(\mathbf{p}^G,\mathbf{q}^G,\mathbf{\tilde{u}}^0)$$

$$(2.15.3)\quad = \int_{\mathbf{p}^0}^{\mathbf{p}^G} \bar{\mathbf{x}}d\mathbf{p} - \int_{\mathbf{z}^0}^{\mathbf{z}^G} \mathbf{D}\mathbf{z}\_e(\mathbf{p},\mathbf{q},\mathbf{\tilde{u}}^0)d\mathbf{z}$$

where $\mathbf{\tilde{u}}^0 = \{u_1^0,\ldots,u_I^0\}$.

The HC measure for a multipart policy may take on several different computational forms. In line (2.14.1), the HC measure is stated as the difference between postpolicy income and the minimum postpolicy expenditure that sustains u_i^0. Alternatively, in line (2.14.2), HC is viewed as the change in income minus the change in minimum expenditure required to sustain u_i^0. Finally, in line (2.14.3), HC is stated as the integral over a set of marginal valuations. In lines (2.15.1) through (2.15.3), analogous alternative forms are stated for the total HC measure.

Definition 2.3 summarizes the structural characteristics of the Hicksian measure of net benefits. The first of these is that the Hicksian measure of net benefits is the difference between two well-defined functions--the linear function $\mathbf{p}\bar{\mathbf{x}}_i$ (or $\mathbf{p}\bar{\mathbf{x}}$) and the expenditure function (see lines (2.14.1) and (2.15.1)). Like the single impact HC, the HC measure for any multipart change from $(\mathbf{p}^0,\mathbf{q}^0)$ to $(\mathbf{p}^G,\mathbf{q}^G)$ is unique and the valuation objective of BC analysis is well-defined. Second, the valid measure of HC encompasses the overall impact of policy in a single, one-step valuation. If applied evaluation techniques permit, an aggregate valuation of the multipart policy is possible via a one-step overall evaluation design.[8] Finally, insofar as lines (2.14.3) and (2.15.3) state the multipart valuation it terms of a line integral, Definition 2.3 suggests a solution to the problem of disaggregating the overall HC measure into a set of valid component valuations. Theorem 2.1 states the (dis)aggregation result for the total HC measure.[7]

Theorem 2.1: Let the policy under consideration be a change from $(\mathbf{p}^0,\mathbf{q}^0)$ to $(\mathbf{p}^G,\mathbf{q}^G)$. Select one of the possible polygonal paths from the vector $\mathbf{q}^0$ to the vector $\mathbf{q}^G$. Assigning subscripts 1 through G according to the order of sequenced component changes, a polygonal path of componentwise changes could be represented as the set of changes from $(\mathbf{p}^0,\mathbf{q}^0)$ to $(\mathbf{p}^1,\mathbf{q}^1)$ to $(\mathbf{p}^2,\mathbf{q}^2)$ to $(\mathbf{p}^3,\mathbf{q}^3)$ and so on until all G impacts are completed with the change from $(\mathbf{p}^{G-1},\mathbf{q}^{G-1})$ to $(\mathbf{p}^G,\mathbf{q}^G)$. Then $hc(\mathbf{q}^G,\mathbf{q}^0)$ and, specifically, the line integral of line (2.15.3) can be decomposed to yield the component evaluations of lines (2.16.2) through (2.16.4),

(2.16.1) $$hc(\mathbf{q}^G,\mathbf{q}^0) = \int_{\mathbf{p}^0}^{\mathbf{p}^G} \bar{\mathbf{x}}d\mathbf{p} - \int_{\mathbf{z}^0}^{\mathbf{z}^G} \mathbf{Dz\_e}(\mathbf{p},\mathbf{q},\tilde{u}^0)d\mathbf{z}$$

(2.16.2) $$= (\mathbf{p}^1 - p^0)\bar{\mathbf{x}} + e(\mathbf{p}^0,\mathbf{q}^0,\tilde{u}^0) - e(\mathbf{p}^1,\mathbf{q}^1,\tilde{u}^0) + \ldots$$

(2.16.3) $$+ (\mathbf{p}^k - \mathbf{p}^{k-1})\bar{\mathbf{x}} + e(\mathbf{p}^{k-1},\mathbf{q}^{k-1},\tilde{u}^0) - e(\mathbf{p}^k,\mathbf{q}^k,\tilde{u}^0) + \ldots$$

(2.16.4) $$+ (\mathbf{p}^G - \mathbf{p}^{G-1})\bar{\mathbf{x}} + e(\mathbf{p}^{G-1},\mathbf{q}^{G-1},\tilde{u}^0) - e(\mathbf{p}^G,\mathbf{q}^G,\tilde{u}^0).$$

Proof. By the fact that $\mathbf{Dzz\_e}_i(.)$ is symmetric, the value of the second line integral in line (2.16.1) is independent of the path of integration; any acceptable path of integration yields the same total valuation. Furthermore, any polygonal path of componentwise changes from $(\mathbf{p}^0,\mathbf{q}^0)$ to $(\mathbf{p}^G,\mathbf{q}^G)$ is a mathematically acceptable path (Apostol). <>[8]

Theorem 2.1 summarizes the important conclusions regarding a valid BCA evaluation design. Most importantly, Theorem 2.1 describes two general approaches to the evaluation of multipart policy. First, as indicated previously by Definition 2.3, a single, one-step evaluation of the overall impact of policy is theoretically valid.[9] Second, as described by lines (2.16.2) through (2.16.4), it is possible to disaggregate the overall policy into its component parts and evaluate the effect of each policy impact separately, thereby obtaining a set of component specific valuations appropriate to regulatory planning. By summing across any valid set of component valuations, the valid aggregate valuation is obtained.

Examining lines (2.16.2) through (2.16.4), there are three general observations regarding the disaggregate approach. First, for a given policy, the valid total valuation obtained by summation of a valid set of component specific valuations is unique. The overall valuation objective is therefore well-defined. Second, to obtain a set of valid disaggregate, impact specific valuations, a sequence of valuation is selected and applied. That is, each of the component impacts changes from $\mathbf{q}_k^0$ to $\mathbf{q}_k^1$ is ordered from first until last and then valued sequentially along a polygonal path that begins at $(\mathbf{p}^0,\mathbf{q}^0)$ and ends with $(\mathbf{p}^G,\mathbf{q}^G)$. Importantly, the structural restrictions imposed by the line integral apply to both market prices and environmental parameters. Finally, component valuations are not generally unique but vary with the particular sequence of valuation that is selected. For example, had a sequence of valuation been selected that reversed the order of componentwise changes, each of the valuations given in lines (2.16.2) through (2.16.4) would be conditioned on different levels of the other G-1 environmental parameters that are subject to policy. By changing the levels of conditioning parameters, the component valuations would also change.

A comparison of the conventional design given by lines (2.13.1) through (2.13.4) with the sequenced, disaggregate VBC design given by lines (2.16.2) through (2.16.4) shows that the IVS and VBC share little in common. IVS evaluates each of the many policy impacts as if each were a single, incremental change in the initial policy vector, $(\mathbf{p}^0, \mathbf{q}^0)$. The disaggregate VBC approach evaluates each component impact as one in a sequence of successive incremental changes. The starting point for the kth policy impact is the post change situation induced by the previous k-1 impacts. Only in the case where all cross partial derivatives of expenditure function vanish are the valuations obtained by IVS the same as those obtained by VBC. Thus, only in the case where the component changes are, in fact, independent in valuation does the disaggregate VBC approach reduce to the conventional design.

Given that it is not difficult to imagine cases of complementarity or competition between market goods or environmental parameters, conditions sufficient for the disaggregate VBC to generally reduce to IVS may be empirically unlikely. However, there may exist common cases where either the total or component error in IVS may be negligible. For example, if only a small number of program impacts are subject to evaluation, it may be that interactions in valuation are unimportant where there are no close or obvious consumption relations between policy impacts.

In view of the likely costs of identifying specific impacts, of sequencing, and of coordinating a valid evaluation effort, it is possible that IVS could prove to be a pragmatically acceptable approach if the error in IVS were shown to be negligible or generally non-existent. To investigate this possibility, the next section begins a qualitative comparison of IVS and VBC outcomes.

The Evaluation of a Small Multipart Policy

The conventional approach to BC evaluation ignores substitution effects between policy components. Recent case studies suggest that failure to account for such interactions results in substantial error [Braeutigam and Noll; Hoehn and Randall]. To test the generality of these empirical results, this section begins a qualitative comparison of IVS and VBC outcomes. The analysis demonstrates that constrained optimization interjects systematic interactions between the impacts of policy. These interactions are most definite in precisely those cases where naive intuition would suggest the absence of substitution effects. In cases where no obvious or close consumption relations exist between policy components, the interaction between policy components is shown to be strictly competitive.

To simplify the initial analysis, the case of a relatively small policy is examined. The implicit assumption is that the resource requirements of the policy are relatively small and that the goods and services necessary to implement a policy are purchased in relatively large markets. Thus, it is assumed that the price impacts of policy are negligible. Analytically, prices are held constant and the resource costs (negative or positive) of policy are represented as the market cost of the market goods and services needed for implementation. This in turn implies that the benefits of policy (positive or negative) can be represented in terms of the expenditure function evaluated over changes in the environmental parameters alone. Consequently, the net benefits of a small policy are

$$(2.17)\quad hc(\mathbf{q}^g, \mathbf{q}^0, u^0) = e(\mathbf{p}^0, \mathbf{q}^0, u^0) - e(\mathbf{p}^0, \mathbf{q}^g, u^0) + C$$

where C is the change in public sector markets goods costs due to the change from $\mathbf{q}^0$ to $\mathbf{q}^g$. If a policy increases public sector market goods costs, C is negative; if policy reduces public sector market goods costs, C is positive. Because market prices are constant, C is simply a sum of market goods expenditures required to carry out the small g impact policy and IVS suffices in the evaluation of costs. Project size alone, however, does not obviously weaken the restrictions on the evaluation of direct policy impacts, $\mathbf{q}^g$.

To determine whether IVS suffices in the context of a small multipart policy, the structure of the expenditure function is examined. One structural approach is to determine the conditions in which policy components are likely to be pairwise complementary, pairwise competitive, or pairwise independent in valuation.

Definition 2.5. Environmental parameters q_h and q_k, h,k, ∈ {1,....,K}, are pairwise complementary in valuation if $\mathbf{D}_{q_h q_k} e(\cdot) < 0$; pairwise competitive if $\mathbf{D}_{q_k q_h} e(\cdot) > 0$; and pairwise independent if $\mathbf{D}_{q_k q_h} e(.) = 0$.

By definition 2.5, if q_h and q_k are complementary in valuation, the component valuation of a change from q_h^0 to q_h^1 is greater if conditioned on a higher level of q_k. If q_h and q_k are competitive, the component valuation of the change in q_h is smaller if conditioned on a higher level of q_k. Only if q_h and q_k are independent does the component valuation of the change in q_h remain invariant with changes in the level of q_k.

To determine the impact of substitution effects on IVS relative to the VBC, consider a policy that changes $\mathbf{q}^0$ to $\mathbf{q}^g$. Using a disaggregate VBC approach equation (2.9) can be restated as

$$(2.18.1)\quad hc(\mathbf{q}^g,\mathbf{q}^0) = e(\mathbf{p}^0,\mathbf{q}^0,\bar{u}^0) - e(\mathbf{p}^0,\mathbf{q}^g,\bar{u}^0) + C$$

$$(2.18.2)\quad = e(\mathbf{p}^0,q_1^0,\ldots,q_k^0,\ldots,q_g^0,\ldots,\bar{u}^0) - e(\mathbf{p}^0,q_1^1,\ldots,q_k^0,\ldots,q_g^0,\ldots,\bar{u}^0) + C_1 + \ldots$$

$$(2.18.3)\quad + e(\mathbf{p}^0,q_1^1,\ldots,q_k^0,\ldots,q_g^0,\ldots,\bar{u}^0) - e(\mathbf{p}^0,q_1^1,\ldots,q_k^1,\ldots,q_g^0,\ldots,\bar{u}^0) + C_k + \ldots$$

$$(2.18.4)\quad + e(\mathbf{p}^0,q_1^1,\ldots,q_k^1,\ldots,q_g^0,\ldots,\mathbf{u}^0) - e(\mathbf{p}^0,q_1^1,\ldots,q_k^1,\ldots,q_g^1,\ldots,\bar{u}^0) + C_g.$$

The IVS evaluation is

$$(2.19.1)\quad IVS(\mathbf{q}^g,\mathbf{q}^0) = \sum_{g=1}^{g} hc(\mathbf{q}_k^1,\mathbf{q}^0)$$

$$(2.19.2) \quad = e(\mathbf{p}^0,q_1^0,\ldots,q_k^0,\ldots,q_g^0,\ldots,\bar{u}^0) - e(\mathbf{p}^0,q_1^1,\ldots,q_k^0,\ldots,q_g^0,\ldots,\bar{u}^0) + C_1$$

$$(2.19.3) \quad + e(\mathbf{p}^0,q_1^0,\ldots,q_k^0,\ldots,q_g^0,\ldots,\bar{u}^0) - e(p^0,q_1^0,\ldots,q_k^1,\ldots,q_g^0,\ldots,\bar{u}^0) + C_k$$

$$(2.19.4) \quad + e(\mathbf{p}^0,q_1^0,\ldots,q_k^0,\ldots,q_g^0,\ldots,\bar{u}^0) - e(\mathbf{p}^0,q_1^0,\ldots,q_k^0,\ldots,q_g^1,\ldots,\bar{u}^0) + C_g.$$

With both the VBC and IVS designs described by equations (2.18) and (2.19), respectively, consider a case where pervasive competition prevails between environmental parameters. If environmental parameters are competitive, line (2.18.2) equals (2.19.2) but all subsequent VBC component valuations are less than those obtained by IVS. Therefore with competition and $q_g^1 > q_g^0$, IVS overstates the benefits of environmental improvement; if $q_g^1 < q_g^0$, IVS understates the (environmental) costs of environmental deterioration. If the q_k are complementary, analogous arguments would show that IVS understates the benefits of environmental improvements and overstates the costs of environmental deterioration. Only if the environmental parameters are somehow independent in valuation would lines (2.18.2) through (2.18.4) be identical to lines (2.19.2) through (2.19.4). By these arguments, then, it is clear that if systematic substitution relations can be identified, the relative outcomes of IVS and a valid VBC approach can be determined.

One hypothesis regarding substitution is that the absence of close or direct relations in consumption might lead to independence in valuation. An intuitively appealing way of expressing this absence of a direct linkage is by means of an additively separable utility function [Green; Deaton and Muelbauer (1980a)],

$$(2.20)\qquad u_i = \sum_{h=1}^{H} u_{ih}(\mathbf{x}_i^h, \mathbf{q}_h),$$

where $\mathbf{q}_h = (q_{h1},\ldots,q_{hN})$ is an N element subvector of $\mathbf{q} = (q_1,\ldots,q_{hn},\ldots,q_{HN})$ $= (q_1,\ldots,q_K)$, $\mathbf{x}_i^h$ is a vector of market goods consumed in conjunction with $\mathbf{q}_h$, and the $u_{ih}(.)$ are strictly increasing and strictly concave for all $i \in \{1,\ldots,I\}$. As simple differentiation shows, the marginal utility of component q_{hn} is unaffected by a change in q_{kr},

$$(2.21)\qquad \mathbf{D}q_{hn}q_{kr}\_u_i = 0.$$

$h \neq k \in \{1,\ldots,H\}$ and $n,r \in \{1,\ldots,N\}$. Thus, if sets of environmental parameters are additively separable, there is no direct interaction between environmental parameters in different activity sets, $u_{ih}(\cdot)$. However, even though this independence holds in the direct form of the utility function, constrained optimization forces quite another substitution relation between additively separable environmental parameters.

Theorem 2.2. Let the preferences of an individual be represented by the utility function given in equation (2.20). Let $u_{ih}(\mathbf{0},\cdot) = 0$, $\mathbf{D}\mathbf{q}_k\_\mathbf{q}_h = \mathbf{0}$, and the cross partial derivatives of u_{ih} be strictly positive. Then

$$(2.22)\qquad e_i(\mathbf{p},\mathbf{q},u_i) = \min_{\mathbf{x}_i} \mathbf{p}\mathbf{x}_i$$

$$\text{s.t. } u_i = \sum_{h=1}^{H} u_{ih}(\mathbf{x}_i^h, \mathbf{q}_h)$$

and the following properties hold for environmental parameters with non-zero valuations:

1. For environmental parameters in different subvectors, the substitution relation is competitive. That is, $Dq_{hn}q_{kr}-e_i(\cdot) > 0$, $h \neq k \in \{1,\ldots,H\}$ and $n,r \in \{1,\ldots,N\}$.

2. For distinct environmental parameters in the same subvector, q_{hn} and q_{hr}, $n \neq r \in \{1,\ldots,N\}$, the substitution relation may be either competitive, independent, or complementary.

Proof. To simplify notation for the purposes of the proof, the notation for household i is suppressed. Rewrite the optimization problem in line (2.22) as a multistage optimization problem [Deaton and Muellbauer]. That is, first, for each $h \in \{1,\ldots,H\}$, solve

$$(2.23) \qquad v_h(\mathbf{p},\mathbf{q}_h,m_h) = \max_{\mathbf{x}^h} \; u_h(\mathbf{x}^h,\mathbf{q}_h)$$

$$\text{s.t. } m_h = \mathbf{p}\mathbf{x}^h.$$

Second, let m_h^*, $h \in \{1,\ldots,H\}$, solve

$$(2.24) \qquad e(\mathbf{p},\mathbf{q},u) = \min_{m_h} \sum_{h=1}^{H} m_h$$

$$\text{s.t. } u = \sum_{h=1}^{H} v_h(\mathbf{p},\mathbf{q}_h,m_h)$$

The Lagrangian for the minimization problem in line (2.24) is

$$(2.25) \qquad L = \sum_{h=1}^{H} m_h + \tau[u - \sum_{h=1}^{H} v_h(\mathbf{p},\mathbf{q}_h,m_h)].$$

The marginal valuation of environmental parameter q_{hn} is[10]

$$(2.26) \qquad \mathbf{D}q_{hn}\_e(\mathbf{p},\mathbf{q},u) = -\tau \mathbf{D}q_{hn}\_v_h(\mathbf{p},\mathbf{q}_h,m_h) < 0$$

for all $h \in \{1,\ldots,H\}$ and $n \in \{1,\ldots,N\}$. The substitution relation is determined by

$$(2.27) \qquad \mathbf{D}q_{hn}q_{kr}\_e(\mathbf{p},\mathbf{q},u) = -\mathbf{D}q_{hn}\_v_h \mathbf{D}q_{kr}\_\tau - \tau \mathbf{D}q_{hn}m_h\_v_h \mathbf{D}q_{kr}\_m_h^*$$

To show that equation (2.25) is positive for additively separable environmental parameters, it must be shown that $\mathbf{D}q_{kr}\_\tau$ and that $\mathbf{D}q_{kr}\_m_h^*$ are negative. Since the expenditure function is decreasing in $\mathbf{q}$, FACT1 is obtained:

FACT1: $\mathbf{D}q_{kr}\_m_h^* < 0$ for some $h \in \{1,\ldots,H\}$.

A second fact comes from the first order conditions (foc) for the minimization problem defined by line (2.24). By differentiating the foc with respect to q_{kr}, equation (2.28) and (2.29) are obtained:

$$(2.28) \qquad -\mathbf{D}q_{kr}\_\tau \mathbf{D}m_h\_v_h = \tau \mathbf{D}m_h m_h\_v_h \mathbf{D}q_{kr}\_m_h^*$$

for all $h \neq k \in \{1,\ldots,H\}$ and

$$(2.29) \qquad -Dq_{kr-}\tau Dm_{k-}v_k = \tau Dm_k m_{k-}v_k Dq_{kr-}m_k^* + \tau Dm_k q_{kr-}v_k.$$

With FACT1 and equations (2.28) and (2.29) as basic restrictions, there are three cases to consider in proving part (1) of Theorem 2.3:

1. Suppose $Dq_{kr-}m_h^* > 0$ for some $h \neq k \in \{1,\ldots,H\}$. Then the righthand side of line (2.28) is negative. This implies that $Dq_{kr-}\tau > 0$ and that $Dq_{kr-}m_h^* > 0$ for all $h \neq k \in \{1,\ldots,H\}$. Furthermore, in line (2.29), it must be that $Dq_{kr-}m_k^* > 0$. But this contradicts FACT1.

2. Suppose $Dq_{kr-}m_h^* = 0$ for some $h \neq k \in \{1,\ldots,H\}$. Then the righthand side of line (2.28) is zero. This implies that $Dq_{kr-}\tau = 0$ and that $Dq_{kr-}m_h^* = 0$ for all $h \neq k \in \{1,\ldots,H\}$. In addition, from line (2.29), $Dq_{kr-}m_k^* > 0$. But this again contradicts FACT1.

3. Suppose $Dq_{kr-}m_h^* < 0$ for some $h \neq k \in \{1,\ldots,H\}$. Then the righthand side of line (2.28) is positive. This implies that $Dq_{kr-}\tau < 0$ and that $Dq_{kr-}m_h^* < 0$ for all $h \neq k \in \{1,\ldots,H\}$. From line (2.29), $Dq_{kr-}m_k^* \gtrless 0$. This is <u>not</u> inconsistent with FACT1.

From cases 1 through 3, it must be that $Dq_{kr-}\tau < 0$ and $Dq_{kr-}m_h^* < 0$ for all $h \neq k \in \{1,\ldots,H\}$. The first conclusion of the Theorem 2.3 therefore follows from line (2.27).

For environmental parameters linked by specific consumption activities, the substitution relation between q_{kn} and q_{kr} is given by

$$(2.30.1)\quad \mathbf{D}q_{kn}q_{kr}\_e(\mathbf{p},\mathbf{q},u) = - \mathbf{D}q_{kn}\_v_k\mathbf{D}q_{kr}\_\tau$$

$$(2.30.2)\qquad\qquad - \tau\mathbf{D}q_{kn}m^*_k\_v_k\mathbf{D}q_{kr}\_m^*_k$$

$$(2.30.3)\qquad\qquad - \tau\mathbf{D}q_{kn}q_{kr}\_v_k.$$

For $n \neq r \in \{1,\ldots,N\}$, the right-hand side of line (2.30.1) is positive but line (2.30.2) may be positive, negative, or zero. Line (2.30.3) is negative. Thus, the substitution relation between q_{kn} and q_{kr} for $n \neq r \in \{1,\ldots,N\}$ may be competitive, complementary, or, if positive and negative quantities just happen to cancel, independent. <>

Theorem 2.2 demonstrates that, with a small number of policy impacts, the qualitative impact of substitution depends upon the particular valuation context. If environmental parameters are linked in specific consumption activities, either competition, complementarity, or independence is possible. However, independence in valuation is likely to occur only if (1) environmental parameters are linked by specific consumption relations and (2) the elements of righthand side of equation (2.30) sum exactly to zero. Given no systematic rationále for an exact canceling of terms, independence appears unlikely.

In a many evaluation contexts, it may be that environmental parameters are not linked by specific consumption relations. For example, additive separability is often an explicit assumption in the household production models [Gorman, Lancaster] and is commonly implicit in econometric analyses [Deaton and Muellbauer (1980a)]. Additive separability across time dated consumption activities is a common presumption of economic analysis [Heckman and MacCurdy]. Additionally, the expected utility property may induce additive separability between environmental parameters. To see this, suppose that the enjoyment of $\mathbf{q}_k$ is associated with a probabilistic outcome $k \in \{1,\ldots,K\}$ that occurs with a probability π_k, $\sum_{k=1}^{K} \pi_k = 1$. Then a household's utility function is

$$(2.31) \qquad u_i = u_i[\sum_{k=1}^{K} \pi_k \cdot (\mathbf{x}_i, \mathbf{q}_k)]$$

Using the expected utility property

$$(2.32) \qquad u_i = \sum_{k=1}^{K} \pi_k u_{ik}(\mathbf{x}_i, \mathbf{q}_k).$$

Corollary 2.2. Suppose that the expected utility property results in the utility function given in line (2.32). Then environmental parameters, $\mathbf{q}_k \in \{1,\ldots,K\}$, are competitive in valuation.

Theorem 2.2 and Corollary 2.2 suggest the sign of the substitution effects that can be expected in different valuation contexts. For environmental parameters separated by space, time, or the expected utility property, competitive effects are certain to arise. Such competitive effects appear to generalize the case study results of Hoehn and Randall and may be extended to encompass the results of Braeutigam and Noll. If environmental parameters are linked by specific and direct consumption interactions, complementarity may be possible but must be strong enough to offset sources of competition. Direct consumption interactions are therefore necessary but not sufficient for complementarity. Finally independence appears unlikely. For independence, direct consumption interactions must be present and sources of competition and complementarity must exactly offset each other. Given the probable background of interaction and substitution, conventional BC procedures are almost certain to routinely produce erroneous BC outcomes.

A Summary of Benefit Cost Evaluation Design

Accurate evaluation of the benefits and costs of regulatory policy requires that the overall impacts be evaluated holistically. The conceptually valid benefit cost design given by Theorem 2.1 suggests two different strategies in actual evaluation. The first approach is described by lines (2.14) and (2.15). The first approach evaluates the entire policy as a single unit or single set of impacts. The second approach is described by lines (2.15.2) through (2.15.4). This later design partitions the overall policy outcome into its component impacts and then values each impact sequentially.

The valid disaggregate design has three essential characteristics. First, the total valuation obtained by summation of a set of valid, component specific valuations is identical to the HC measure obtained with the single step design. Thus, the overall or aggregate valuation objective is clear and well-defined. Second, to obtain the valid aggregate valuation via a disaggregate design, a sequence of valuation is selected and applied. A valid (polygonal) sequence of valuation arrays the components of policy from first until last and then evaluates each impact sequentially by changing one component at a time from its initial to its postpolicy level. The valid aggregate valuation is obtained by summation of the sequenced, component specific valuations. Finally, the component valuations are not unique but are conditioned on the selected sequence of valuation. Generally, each sequence of valuation yields a different set of component specific valuations.

Because the restrictions imposed by a valid design are severe, a qualitative analysis was carried out to assess the impact of conventional procedures on benefit cost outcomes. The analysis reached three conclusions. First, if environmental parameters are additively separable, competitive effects are certain. Such separability may be induced by household technology, by spatial or temporal separation, or by uncertainty via the expected utility property. In these cases, conventional BC procedures can be expected to systematically overstate the net benefits of policy change.

Second, if environmental parameters are linked by direct consumption interactions, complementarity is possible. However, complementary effects must be strong enough to overcome the sources of competition that remain operative. Direct consumption linkages are therefore necessary but not sufficient for complementary effects.

Finally, independence in valuation is possible if (1) environmental parameters are linked by specific consumption relations and (2) sources of complementarity and competition just happen to sum exactly to zero. Given no general rationale for such a fortuitous outcome, independence appears unlikely. Insofar as the conditions for competition and, to a lesser extent, for complementarity, seem far more probable than those required for independence, conventional benefit cost procedures are almost certain to routinely result in erroneous benefit cost outcomes.

Endnotes

1. Silberberg gives an overview of the envelope function approach. Chipman and Moore, Small and Rosen, and Hanemann apply the approach to various welfare measurement problems.

2. The description of households, firms, and pricing is similar to that described by Arrow and Hahn. For additional depth on aspects of household production, see Majid, Sinden, and Randall or Bockstael and McConnell.

3. Environmental amenities are broadly defined to include a full range of unpriced, parametric qualities and quantities that impact directly on the utility possibilities of individual households. Such parameters may be legal, institutional, or physical in nature.

4. The aggregate production set is assumed to be convex and compact. Additional properties are detailed in the next Chapter.

5. A more complete description of these equilibrium prices is given in Chapter III.

6. **Ds_** is the first partial derivative operator where the derivative is taken with respect to the vector **s**. **Dss_** is the second derivative operator with respect to the vector **s**. **Dsr_** = **Dr_**(**Ds_**) is the second cross partial derivative operator with respect to the vector **r**.

7. An identical disaggregation result would hold for the $hc_i(\mathbf{q}^G,\mathbf{q}^0)$, $i \in \{1,\ldots,I\}$. For both the total and individual cases, the structure and proof of the (dis)aggregation design depend upon the structure of $e_i(\mathbf{p},\mathbf{q},u_i)$.

8. The end of a proof is indicated with a <>.

9. Contingent valuation [Randall, Ives, and Eastman; Brookshire, Ives, and Schulze] provides one approach to encompass the overall impact of policy.

10. The relevant Kuhn-Tucker first order conditions are assumed to be met with equality.

Chapter III

ASSESSING THE POSSIBILITY OF SYSTEMATIC ERROR IN CONVENTIONAL BENEFIT COST OUTCOMES

With routine public sector use of benefit cost analysis, conventional BC procedures may be simultaneously and independently applied to a large number of policy alternatives. Results of the last Chapter indicate that the conventional design is almost certain to result in erroneous, component specific BC outcomes. Though this theoretical finding generalizes case study evidence [Hoehn and Randall; Braeutigam and Noll], there does exist the possibility that overall, across the many alternatives posed by a policy agenda, the errors induced by IVS may cancel or average out by some law of large numbers. If such errors do in fact cancel, IVS may on average approximate a valid BC outcome.

The problem taken up in this Chapter is whether the errors of the IVS design can be expected to cancel or average out as the number of evaluated policy impacts becomes large. To capture the essential features of the large number case, the first section of this Chapter defines a policy environment that is "epsilon augmentable." Using the framework developed in the last Chapter, IVS procedures are found to systematically overstate the desirability of policy change. Left unclear, however, is whether conventional procedures actually misidentify net loss policies as potential Pareto improvements.

To determine whether conventional procedures actually misstate the sign of BC outcomes, it is necessary to refine the description of the economy. The topological properties of aggregate production and consumption are of particular interest. Thus, the second section details the structure of aggregate demand and supply and summarizes the relevant general equilibrium results.

To extend the results of the last Chapter, the HC measure is defined in a manner appropriate to the explicit general equilibrium structure.

The next two sections derive and analyze the conventional and valid BC designs. The third section defines both the conventional and valid measures. The structural restrictions of the valid design are shown to be virtually identical to those obtained in the structurally more simple economy of Chapter II. The fourth section extends the initial large number theorem. For a general case where the marginal costs of policy change are positive, conventional procedures are shown to misidentify net loss policies as potential Pareto improvements.

An Initial Comparison of Benefit Cost Outcomes in the Large Number Case

In a contemporary setting, BC analysis may be applied to a large number of policy alternatives under the authority of a large number of different, autonomous public agencies. Conventional procedures, however, ignore the overall policy agenda and view each policy component or small set of components as the next marginal increment to an initial set of baseline conditions. When evaluated as the next marginal increment, a large number of policy components are likely to appear beneficial on benefit cost terms. To formalize this notion of a large number of apparently beneficial components, the policy environment is described as "epsilon augmentable."

Definition 3.1: A policy environment is epsilon augmentable if for a G impact policy and real criterion $\in > 0$ it is possible to find an additional component q_{G+1} and component policy change from q^0_{G+1} to q^1_{G+1}, $q^0_{G+1} \neq q^1_{G+1}$, such that the independently evaluated net benefits of the component change exceed the criterion epsilon. That is, $hc(\mathbf{q}^1_{G+1},\mathbf{q}^0) > \epsilon$.

By Definition 3.1, policy is epsilon augmentable if it is possible to append any G impact change with an additional component change from q^0_{G+1} to q^1_{G+1} that is valued nontrivially in independent valuation. In this epsilon augmentable policy environment, one can begin to investigate whether or not the errors introduced by IVS cancel or average out as the number of policy components becomes large.

Theorem 3.1: Let the policy environment be epsilon augmentable and suppose that prices are computed for compensated equilibria.[1] Let only components with independent valuations greater than epsilon be considered for implementation. Then if G is the number of policy impacts under consideration, there is a finite integer N such that for G > N, IVS overstates the Hicksian compensating measure associated with the policy agenda as well as the net benefits of at least some subset of components.

Proof. To show that IVS overstates the HC measure of benefits for some G > N impacts, note first that the IVS measure of benefits is not bounded; for each additional component included in the policy agenda, the IVS measure of compensation increases by at least epsilon.

The HC measure, however, is bounded. To see this, suppose first that some positive quantity of the numeraire is essential in order allow the economy to sustain $\mathbf{Q}^0$. Then the HC measure is bounded by $\bar{x}_1 = \sum_{i=1}^{I} \bar{x}_{i1}$. That is, for any number of impacts G, there is a real number $\delta^G > 0$ such that

$$(3.1) \qquad \bar{x}_1\delta^G + \tilde{p}^G\tilde{x} - e(\mathbf{p}^G,\mathbf{q}^G,\tilde{u}^0) = 0$$

where $\tilde{x} = (\bar{x}_2,\ldots,\bar{x}_J)$ and $\tilde{p}^G = (p_2^G,\ldots,p_J^G)$. Then $(1 - \delta^G)\bar{x}_1$ is bounded by $\bar{x}_1$. For $N = \bar{x}_1/\epsilon$ and $G > N$ impacts,

$$(3.2.1) \qquad ivs(\mathbf{q}^G,\mathbf{q}^0) > G\epsilon$$

$$(3.2.2) \qquad > \bar{x}_1$$

$$(3.2.3) \qquad > hc(\mathbf{q}^G,\mathbf{q}^0).$$

That is, for G larger than $N = \bar{x}_1/\epsilon$, IVS is certain to exceed the valid HC measure.

If the initial numeraire is inessential it may not be possible to compensate solely by a portion of $\bar{x}_1$ and eliminate the gain due to $(\mathbf{p}^G,\mathbf{q}^G)$. In this case, the numeraire is not useful as a means of comparison and it is necessary to redefine HC in terms of a vector of resources that are essential to sustain $\tilde{\mathbf{u}}^0$ [cf., Randall and Stoll, 1980b]. Certainly the endowment vector, $\bar{\mathbf{x}}$, as a whole is essential. In this case, normalize prices so that $p_h = p_h/[\sum_{j=1}^{J} p_j]$.

Define the HC measure as

$$(3.3) \qquad hc(\mathbf{q}^G,\mathbf{q}^0) = (1 - \delta^G)\mathbf{p}^G\bar{\mathbf{x}}$$

where $\mathbf{p}^G\bar{\mathbf{x}}\delta^G - e(\mathbf{p}^G,\mathbf{q}^G,\bar{u}^0) = 0$ and $hc(\mathbf{q}^G,\mathbf{p}^G)$ is bounded by $\sum_{j=1}^{J} \bar{x}_j = B^*$ since $p_j < 1$.

Define the IVS aggregate measure as

$$(3.4) \qquad ivs(\mathbf{q}^G,\mathbf{q}^0) = \sum_{g=1}^{G} (1 - \delta_g)\mathbf{p}_g^1\bar{\mathbf{x}}$$

where $\mathbf{p}_g^1\bar{\mathbf{x}}\delta_g - e(\mathbf{p}_g^1,\mathbf{q}_g^1,\bar{u}^0) = 0$. By assumption, $(1 - \delta_g)\mathbf{p}_g^1\bar{\mathbf{x}} > \epsilon$. Therefore, for $N = B^*/\epsilon$ and $G > N$ impacts,

$$(3.5.1) \qquad ivs(\mathbf{q}^G,\mathbf{q}^0) > G\epsilon$$

$$(3.5.2) \qquad > B^*$$

$$(3.5.3) \qquad > hc(\mathbf{q}^G,\mathbf{q}^0).$$

Therefore, in either the numeraire or vector compensation case, there is a finite N and G > N large enough such that the IVS measure overstates the valid Hicksian compensating measure of net benefits.

Finally, in either the numeraire or vector compensation case, the sum of the valid set of component benefits forms a bounded sequence of real numbers as G increases. Thus, as G becomes large, the valid measure of component benefits due to the Gth impact must either (1) approach zero or (2) become negative. Because the IVS measure of component benefits exceeds $\epsilon > 0$, IVS procedures overstate component benefits for at least some subset of component impacts. <>

In interpreting Theorem 3.1, there are two points to note. First, Theorem 3.1 does not determine a least upper bound or smallest number of impacts G for which IVS overstates Hicksian compensation. However, in a probabilistic sense, the smallest number of impacts for which IVS overstates a VBC outcome could be taken as a random number on the set on integers {2,...,N}. In this sense, Theorem 3.1 certainly demonstrates that the probability that IVS exceeds a VBC outcome converges to one as G increases.[2] Less formally, one would expect that the probability that IVS exceeds a VBC outcome would tend to increase as G increases.

Second, given the large number result, IVS evaluation appears likely to introduce an additional degree of instability into policy selection process than would otherwise be the case with a VBC strategy. That is, by overstating net benefits, IVS overstates the desirability of policy change, the desirability of policy action. For example, it seems quite possible that a policy selection process may take the relative size of net compensation as a measure of desirability and may perhaps trade off positive benefit cost results against other criteria. If so, IVS overstates the desirability of policy action. Furthermore, if actually implemented, the policy agenda as well as at least a subset of policy components are likely to be found less desirable than anticipated. Ex post evaluation may indicate grounds for a policy reversal.[3]

The Hicksian Compensating Measure in a General Equilibrium Setting

Theorem 3.1 provides an important initial result: IVS procedures overstate the net benefits of policy change as the number of evaluated impacts becomes large. Left unclear, however, is whether conventional procedures actually identify a subset of policy components as having positive net benefits when, in fact, the valid measure of net benefits is negative. To investigate the relative size of aggregate benefits and costs, a more detailed analysis of economic structure is necessary. Thus, in the first subsection, the properties of aggregate demand and supply are detailed and several relevant general equilibrium results are summarized. In the second subsection, the Hicksian compensating measure is used to construct a BC design appropriate to a general equilibrium setting.

Consumption, Production, and Policy

The objective of this subsection is to detail the economy described in the last Chapter and to summarize several general equilibrium results that are useful in analyzing the large number case. Thus, the starting point is the economy composed of households, firms, and regulatory agencies as described in the last Chapter.[4]

As in the previous Chapter, household preferences are summarized by a utility function, $u_i = u_i(\mathbf{x}_i, \mathbf{q})$, that is strictly increasing, continuous, and strictly quasiconcave. The set of household demands that yield utility equal to or greater than u_i at environmental quality level $\mathbf{q}$ is $\mathbf{X}_i(\mathbf{q}, u_i) \subset \mathbf{R}^+$. Thus, a household's expenditure function is

$$(3.6) \qquad e_i(\mathbf{p},\mathbf{q},u_i) = \{e_i \mid e_i = \min_{\mathbf{x}_i} \mathbf{p}\mathbf{x}_i \text{ s.t. } x_i \in \mathbf{X}_i(\mathbf{q},u_i)\}$$

An aggregate consumption bundle is $\mathbf{x} = \sum_{i=1}^{I} \mathbf{x}_i$ and the set of aggregate demands that yield a utility allocation not dominated by the allocation $\tilde{\mathbf{u}} = \{u_1,\ldots,u_I\}$ at environmental quality $\mathbf{q}$ is $\mathbf{X}(\mathbf{q},\tilde{\mathbf{u}})$. As in the previous Chapter, the aggregate expenditure required to maintain the utility allocation $\tilde{\mathbf{u}}$ is, at prices $\mathbf{p}$ and environmental parameters $\mathbf{q}$,

$$(3.7) \qquad e(\mathbf{p},\mathbf{q},\tilde{\mathbf{u}}) = \sum_{i=1}^{I} e_i(\mathbf{p},\mathbf{q},u_i), \quad u_i \in \tilde{\mathbf{u}}.$$

A firm $f \in \{1,\ldots,F\}$ produces a netput $\mathbf{y}_f \in \mathbf{R}^J$ using a convex and differentiable transformation function $T_f(\mathbf{y}_f,\mathbf{q}_f) \leq 0$ where T_f is strictly increasing in $\mathbf{y}_f$ and $\mathbf{q}_f$ ($\mathbf{D}\mathbf{y}_{f\_}T_f > \mathbf{0}$, $\mathbf{D}\mathbf{q}_{f\_}T_f > 0$) and $T_f(\mathbf{0},\mathbf{0}) = 0$. The vector $\mathbf{q}_f \in \mathbf{R}^K$ denotes the amount of environmental improvement (impairment) produced by firm $f \in \{1,\ldots,F\}$. The background or natural level of nonmarket goods is normalized at $\mathbf{0}$. To capture the notion of materials balance [Kneese, Ayres, and d'Arge], it is assumed that for any $\mathbf{y}_f^1 \geq 0$, there is a $\mathbf{q}_f^1 < 0$ such that $T_f(\mathbf{y}_f^1,\mathbf{q}_f) > 0$ for all $\mathbf{q}_f \leq \mathbf{q}_f^1$. Across firms the allocation of environmental production is $\tilde{\mathbf{q}} = \{\mathbf{q}_1,\ldots,\mathbf{q}_F\}$ and the level of environmental quality perceived by households is $\mathbf{q} = \mathbf{g}(\tilde{\mathbf{q}})$, $\mathbf{g}{:}\mathbf{R}^F X \mathbf{R}^K \text{->} \mathbf{R}$, where $\mathbf{g}$ is continuous and monotonically increasing. For a given firm, the market goods production set is $\mathbf{Y}_f(\tilde{\mathbf{q}})$ where $\mathbf{Y}_f(\tilde{\mathbf{q}}') = \mathbf{Y}_f(\tilde{\mathbf{q}}'')$ if and only if $\mathbf{q}_f' = \mathbf{q}_f''$.

An aggregate netput vector is a vector $\mathbf{y} = \sum_{f=1}^{F} \mathbf{y}_f$. At a given $\tilde{\mathbf{q}}$, the aggregate production set is

$$(3.8) \qquad \mathbf{Y}(\tilde{\mathbf{q}}) = \{\mathbf{y} \mid \mathbf{y} = \sum_{f=1}^{F} \mathbf{y}_f,\ \mathbf{y}_f \in \mathbf{Y}_f(\tilde{\mathbf{q}})\}.$$

The aggregate production set for both market and nonmarket goods is

$$(3.9) \qquad \mathbf{W} = \{(\mathbf{y},\mathbf{q}) \mid \mathbf{y} = \sum_{f=1}^{F} \mathbf{y}_f,\ \mathbf{y}_f \in \mathbf{Y}_f(\tilde{\mathbf{q}}),\ \mathbf{q} = \mathbf{g}(\tilde{\mathbf{q}}),\ \tilde{\mathbf{q}} \in \mathbf{R}^F X \mathbf{R}^K\}.$$

A fundamental assertion of economic models is scarcity; that something cannot be produced from nothing. To impose this notion of scarcity on the present economic model, it is asserted that a positive level of market and nonmarket goods cannot be produced without an initial endowment of resources,[5]

$$(3.10) \qquad \mathbf{W} \cap \{(\mathbf{y},\mathbf{q}) \mid (\mathbf{y},\mathbf{q}) \geq \mathbf{0}\} = \{\mathbf{0}\}.$$

Given resource endowments, $\bar{\mathbf{x}}$, the feasible production sets are

$$(3.11) \qquad \hat{\mathbf{W}} = \{(\mathbf{y},\mathbf{q}) \mid \mathbf{y} + \bar{\mathbf{x}} \geq \mathbf{0},\ (\mathbf{y},\mathbf{q}) \in \mathbf{W}\}$$

and

$$(3.12) \qquad \hat{\mathbf{Y}}(\breve{\mathbf{q}}) = \{\mathbf{y} \mid \mathbf{y} + \bar{\mathbf{x}} \geq \mathbf{0},\ \mathbf{y} \in \mathbf{Y}(\breve{\mathbf{q}})\}.$$

Given the assumptions made thus far, both $\hat{\mathbf{W}}$ and $\hat{\mathbf{Y}}(\breve{\mathbf{q}})$ are compact.[6]

For a nonmarket allocation $\breve{\mathbf{q}}$ and a utility allocation $\breve{\mathbf{U}} = \{u_1,\ldots,u_I\}$, define the set of excess demands as

$$(3.13) \qquad \mathbf{D}(\breve{\mathbf{q}},\breve{\mathbf{U}}) = \{\mathbf{d} \mid \mathbf{d} = \mathbf{x} - \mathbf{y} - \bar{\mathbf{x}},\ \mathbf{x} \in \mathbf{X}(\breve{\mathbf{q}},\breve{\mathbf{U}}),\ \mathbf{y} \in \mathbf{Y}(\breve{\mathbf{q}}),\ \mathbf{q} = \mathbf{g}(\breve{\mathbf{q}})\}.$$

At $(\breve{\mathbf{q}},\breve{\mathbf{U}})$ the set of feasible excess demands is

$$(3.14) \qquad \hat{\mathbf{D}}(\breve{\mathbf{q}},\breve{\mathbf{U}}) = \{\mathbf{d} \mid \mathbf{d} \leq \mathbf{0},\ \mathbf{d} \in \mathbf{D}(\breve{\mathbf{q}},\breve{\mathbf{U}})\}.$$

$\hat{\mathbf{D}}(\breve{\mathbf{q}},\breve{\mathbf{U}})$ is compact and convex.[7]

At $\tilde{q}$, a utility allocation $\tilde{u}$ is feasible if $\hat{D}(\tilde{q},\tilde{u})$ is nonempty. The utility allocation is conditionally Pareto efficient if $\tilde{u}$ is feasible and not dominated by any other feasible allocation. Given the assumptions on individual preferences, if $\tilde{u}$ is Pareto efficient, then $D(\tilde{q},\tilde{u})$ and $\hat{D}(q,\tilde{u})$ are disjoint from $\{d \mid d < 0\}$.

The role of regulatory agencies is to control the allocation of environmental impairment $\tilde{q}$ in order to regulate the ambient level of environmental parameters, $q = g(\tilde{q})$. Given $\tilde{q}$, the profits or losses of firms are distributed via a net dividend-tax share, t_i, where the subscript i indicates the dividend-tax share of the ith household and $\sum_{i=1}^{I} t_i = 1$. Given t_i the dividend-tax of the ith household is $t_i py$.[8] For simplicity, the discussion below is carried out for a dividend-tax share based on a household's relative income, $t_i = p\bar{x}_i/p\bar{x}$.

An initial competitive equilibrium is a price vector $p^0 > 0$, a consumption allocation $\tilde{x}^0 = \{x_i^0 \mid i \in (1,\ldots,I)\}$, and a production allocation $\tilde{y}^0 = \{y_f^0 \mid f \in (1,\ldots,F)\}$ such that

(a) $d^0 = x^0 - y^0 - \bar{x} = 0$,

(b) py_f^0 maximizes $p^0 y_f$ subject to $y_f \in Y_f(\tilde{q}^0)$, and

(c) x_i^0 maximizes $u_i(x_i,\tilde{q}^0)$ subject to $p^0 x_i \le p^0 \bar{x}_i + t_i^0 p^0 y_f^0$.

Given the described economic structure, it can be shown that, for some $\tilde{q}^0$, an initial competitive equilibrium exists and is conditionally Pareto efficient.[9] That is, atomistic exchange eliminates all feasible gains from trade in market goods given the level of environmental regulatory controls, $\tilde{q}^0$. Below, it is assumed that the initial allocation of market and environmental goods, $\{\breve{\mathbf{x}}^0, \breve{\mathbf{q}}^0\}$, is sustained by a competitive equilibrium.

Conditional Pareto efficiency suggests the possibility of a Pareto or welfare improvement through some reallocation of environmental controls. In this context, an agency may use benefit cost analysis to determine whether a given reallocation is beneficial.

<u>The Hicksian Compensating Measures</u>

In the general setting, the Hicksian compensating measure is the amount of numeraire compensation that would leave individuals at the initial utility allocation at the post policy level of nonmarket goods. In other words, if individuals are collectively compensated by the HC measure, the initial utility allocation is conditionally Pareto efficient at the <u>post policy</u> level of nonmarket goods.

Definition 3.2: Let commodity x_1 be the numeraire, $\breve{\mathbf{q}}^0$ the initial allocation of regulatory controls, and $\breve{\mathbf{u}}^0$ the initial utility allocation. Let $\breve{\mathbf{q}}$ be either a single or multipart policy alternative. The aggregate Hicksian compensating measure is a real number $hc = hc(\breve{\mathbf{q}}, \breve{\mathbf{q}}^0)$ such that for the vector $\mathbf{hc} = \mathbf{hc}(\breve{\mathbf{q}}, \breve{\mathbf{q}}^0) = [hc(\breve{\mathbf{q}}, \breve{\mathbf{q}}^0), 0, \ldots, 0]$,

$$(3.15) \qquad \{\mathbf{d} + \mathbf{hc} \mid \mathbf{d} \in \mathbf{D}(\breve{\mathbf{q}}, \breve{\mathbf{u}}^0)\} \cap \{\mathbf{d} \mid \mathbf{d} \le \mathbf{0}\} = \{\mathbf{0}\}$$

where $\mathbf{q} = \mathbf{g}(\breve{\mathbf{q}})$. For a single impact policy, $\mathbf{q}_k^1$, the relevant Hicksian measures are $hc_k = hc_k(\breve{\mathbf{q}}_k^1, \breve{\mathbf{q}}^0)$ and $\mathbf{hc}_k = \mathbf{hc}(\breve{\mathbf{q}}_k^1, \breve{\mathbf{q}}^0)$. For a multipart policy, $\mathbf{q}^G$, the relevant Hicksian measures are $hc^G = hc(\breve{\mathbf{q}}^G, \breve{\mathbf{q}}^0)$ and $\mathbf{hc}^G = \mathbf{hc}(\breve{\mathbf{q}}^G, \breve{\mathbf{q}}^0)$.

As in Chapter II, the HC measures can be used to identify a regulatory policy that is a potential Pareto improvement (PPI) from among a set of policies that include potentially Pareto inferior (PPF) alternatives. Simply put, a policy proposal is a PPI if the initial utility allocation can be sustained with a surplus of at least some market goods. More rigorously, a regulatory policy is a PPI if there is a $\mathbf{d} \in \hat{\mathbf{D}}(\tilde{\mathbf{q}},\tilde{\mathbf{u}}^0)$ and $\mathbf{d} < 0$. A regulatory policy is PPF if $\hat{\mathbf{D}}(\tilde{\mathbf{q}},\tilde{\mathbf{u}}^0) = \emptyset$. For PPF policies, the utility damage may be so devastating that the initial utility allocation can not be sustained for any hc < 0. However, since the focus below is on distinguishing PPI from PPF, these nonfinite compensation cases are ignored. Theorem 2.1 shows regulatory change is a PPI if and only if hc > 0.

Theorem 3.2: Let $\tilde{\mathbf{q}}^0$ be the initial allocation of nonmarket controls and $\tilde{\mathbf{u}}^0$ the initial utility allocation. Let $\tilde{\mathbf{q}}$ be either a single or multi-impact policy alternative. The regulatory change from $\tilde{\mathbf{q}}^0$ to $\tilde{\mathbf{q}}$ is a potential Pareto improvement if and only if there exists a unique hc > 0 such that

$$(3.16) \qquad \{\mathbf{d} + \mathbf{hc} \mid \mathbf{d} \in \mathbf{D}(\tilde{\mathbf{q}},\tilde{\mathbf{u}}^0)\} \cap \{\mathbf{d} \mid \mathbf{d} \leq \mathbf{0}\} = \{\mathbf{0}\}$$

Proof. (See appendix)

Because $\tilde{\mathbf{u}}^0$ is Pareto efficient when the economy is compensated by hc, there is a price vector $\mathbf{p} > 0$ such that (1) household expenditure is minimized over $\mathbf{X}_i(\tilde{\mathbf{q}},\tilde{\mathbf{u}}^0)$ at $\mathbf{x}_i$ for all $i \in \{1,\ldots,I\}$, (2) profits are maximized over $\mathbf{Y}_f(\tilde{\mathbf{q}})$ at $\mathbf{y}_f$ for all $f \in \{1,\ldots,F\}$, and (3) $0 = \mathbf{px} - \mathbf{py} - \mathbf{p}\bar{\mathbf{x}} + \text{hc}$ (cf., Arrow and Hahn). For a single impact policy, $\mathbf{q}_k^1$, this price vector is denoted $\mathbf{p}_k$ and the optimal choices of the individual and firm are, respectively, $\mathbf{x}_{ik}$ and $\mathbf{y}_{fk}$. For a multipart policy, $\mathbf{q}^G$, the equilibrium price vector is $\mathbf{p}^G$ and the optimal choices of the individual and firm are denoted $\mathbf{x}^G$ and $\mathbf{y}^G$.

Definition 3.3: For the regulatory change $\tilde{\mathbf{q}}^0$ to $\tilde{\mathbf{q}}$, the Hicksian compensating measure for a household i is a real number hc_i such that

$$(3.17.1) \quad hc_i(\tilde{\mathbf{q}},\tilde{\mathbf{q}}^0) = \mathbf{p}\bar{\mathbf{x}}_i + t_i\mathbf{p}\mathbf{y} - \mathbf{p}\mathbf{x}_i$$

$$(3.17.2) \quad = \mathbf{p}\bar{\mathbf{x}}_i + t_i\mathbf{p}\mathbf{y} - e_i(\mathbf{p},\mathbf{q},u_i^0)$$

For a single impact policy, the household's compensating measure is denoted $hc_{ik} = hc_{ik}(\tilde{\mathbf{q}}_k,\tilde{\mathbf{q}}^0)$. For the multipart policy, the household's compensating measure is $hc_i^G = hc_i(\tilde{\mathbf{q}}^G,\tilde{\mathbf{q}}^0)$.

As in Definitions 2.1 and 2.3, Definition 3.3 indicates that the HC measure is the difference between the household's income at the compensated postpolicy price vector $\mathbf{p}$ and the minimum income required to sustain $\tilde{u}^0$ at $(\mathbf{p},\mathbf{q})$. By noting that initial income equals the initial expenditure required to maintain u_i^0, the Hicksian compensating measure can also be written

$$(3.18) \quad hc_i(\tilde{\mathbf{q}},\tilde{\mathbf{q}}^0) = (\mathbf{p} - \mathbf{p}^0)\bar{\mathbf{x}}_i + t_i\mathbf{p}\mathbf{y} - t_i^0\mathbf{p}^0\mathbf{y}^0 - [e_i(\mathbf{p},\mathbf{q},u_i^0) - e_i(\mathbf{p}^0,\mathbf{q}^0,u_i^0)]$$

By line (3.18) the Hicksian compensating measure can be written as the (1) the change in rental income plus (2) the change in dividends or taxes minus

(3) the change in minimum expenditure required to sustain the initial utility level. If $hc_i > 0$, a household realizes the initial utility level with an expenditure less than the postpolicy level of income and the change is an improvement. If $hc_i < 0$, the initial utility level could not be realized at the postpolicy level of income and the household would be made worse off by the change. If each household is compensated by hc_i, the set $\{\tilde{\mathbf{u}},\mathbf{p},\tilde{\mathbf{x}},\tilde{\mathbf{q}}\}$ is a postpolicy compensated equilibrium and $hc = \sum_{i=1}^{I} hc_i$. By Theorem 3.2, if $hc > 0$, the change from $\tilde{\mathbf{q}}^0$ to $\tilde{\mathbf{q}}^1$ is a PPI.

Finally, the results of Varian (1975) can be used to show that given $\tilde{\mathbf{q}}$ and $\tilde{\mathbf{u}}^0$, the compensated equilibrium is unique. Compensation, hc_i, depends only upon the initial utility allocation and the postpolicy regulatory control $\tilde{\mathbf{q}}$. That is, in a comparative static setting, hc_i and hc are conceptually independent of the path of regulatory changes used to accomplish the change in nonmarket goods.

Generalized Conventional and Valid Benefit Cost Designs

The generalized Hicksian benefit measures defined above provide the basic elements for both the conventional and valid BC designs. As discussed in Chapter 2, conventional and valid approaches are identical for a single impact policy. However, for a multipart policy, conventional and valid designs diverge. The IVS net benefit measure is the sum of single impact benefit measures. The valid design is derived directly from the Hicksian benefit measure defined on a multipart policy.

To construct the IVS design for a multipart policy, Definition 3.4 uses the single impact or component specific valuations described in Definitions 3.2 and 3.3.

Definition 3.4: Let policy be a G impact set of changes beginning at $\tilde{\mathbf{q}}^0$ and ending at $\tilde{\mathbf{q}}^G$. The postpolicy level of environmental quality is $\mathbf{q}^G = \mathbf{g}(\tilde{\mathbf{q}}^G)$,

$$(3.19) \qquad \mathbf{q}^G = (q_1^1,\ldots,q_k^1,\ldots,q_G^1,q_{G+1}^0,\ldots,q_K^0).$$

The aggregate compensating measure given by independent valuation and summation (IVS) is

$$(3.20.1) \qquad IVS(\tilde{\mathbf{q}}^G,\tilde{\mathbf{q}}^0) = \sum_{k=1}^{K} \sum_{i=1}^{I} hc_{ik}$$

$$(3.20.2) \qquad = \mathbf{p}_1^1\bar{\mathbf{x}} + \mathbf{p}_1^1\mathbf{y}_1 - e(\mathbf{p}_1^1,\mathbf{q}_1^1,\tilde{\mathbf{u}}^0) + \ldots$$

$$(3.20.3) \qquad + \mathbf{p}_k^1\bar{\mathbf{x}} + \mathbf{p}_k^1\mathbf{y}_k - e(\mathbf{p}_k^1,\mathbf{q}_k^1,\tilde{\mathbf{u}}^0) + \ldots$$

$$(3.20.4) \qquad + \mathbf{p}_G^1\bar{\mathbf{x}} + \mathbf{p}_G^1\mathbf{y}_G - e(\mathbf{p}_G^1,\mathbf{q}_G^1,\tilde{\mathbf{u}}^0)$$

where $\mathbf{y}_k$ and $\mathbf{x}_k$ denote, respectively, the aggregate supply and aggregate demand vectors at a postpolicy compensated equilibrium subsequent to a single impact change from $\tilde{\mathbf{q}}^0$ to $\tilde{\mathbf{q}}_k^1$.

To develop a valid alternative to the IVS design, Theorem 3.3 also begins with Definitions 3.2 and 3.3. However, the starting point for a valid evaluation of multipart policy is the HC measure defined over a multipart policy.

Theorem 3.3: Let the policy under consideration be a change from $\tilde{\mathbf{q}}^0$ to $\tilde{\mathbf{q}}^G$. Select a sequence of controls from $\tilde{\mathbf{q}}^0$ to $\tilde{\mathbf{q}}^G$ such that the environmental impacts, $\mathbf{q}^G = (q_1^1, \ldots, q_G^1, q_{G+1}^0, \ldots, q_K^0)$, are accomplished sequentially by changing $\mathbf{q}^0$ to $\mathbf{q}^1$ first, $\mathbf{q}^1$ to $\mathbf{q}^2$ second, $\mathbf{q}^2$ to $\mathbf{q}^3$ third, and so on until all G impacts are accomplished with the change from $\mathbf{q}^{G-1}$ to $\mathbf{q}^G$. A valid design to obtain the total and component specific Hicksian compensating measures associated with a multipart policy is

(3.21.1) $\quad hc(\tilde{\mathbf{q}}^G, \tilde{\mathbf{q}}^0) = \mathbf{p}^G\bar{\mathbf{x}} + \mathbf{p}^G\mathbf{y}^G - \mathbf{p}^G\mathbf{y}^G$

(3.21.2) $\quad = \sum_{k=1}^{G} hc(\tilde{\mathbf{q}}^k, \tilde{\mathbf{q}}^{k-1})$

(3.21.3) $\quad = (\mathbf{p}^1 - \mathbf{p}^0)\bar{\mathbf{x}} + \mathbf{p}^1\mathbf{y}^1 - \mathbf{p}^0\mathbf{y}^0$

$$+ e(\mathbf{p}^0, \mathbf{q}^0, \tilde{u}^0) - e(\mathbf{p}^1, \mathbf{q}^1, \tilde{u}^0)$$

(3.21.4) $\quad + (\mathbf{p}^k - \mathbf{p}^{k-1})\bar{\mathbf{x}} + \mathbf{p}^k\mathbf{y}^k - \mathbf{p}^{k-1}\mathbf{y}^{k-1}$

$$+ e(\mathbf{p}^{k-1}, \mathbf{q}^{k-1}, \tilde{u}^0) - e(\mathbf{p}^k, \mathbf{q}^k, \tilde{u}^0)$$

(3.21.5) $\quad + (\mathbf{p}^G - \mathbf{p}^{G-1})\bar{\mathbf{x}} + \mathbf{p}^G\mathbf{y}^G - \mathbf{p}^{G-1}\mathbf{y}^{G-1}$

$$+ e(\mathbf{p}^{G-1}, \mathbf{q}^{G-1}, \tilde{u}^0) - e(\mathbf{p}^G, \mathbf{q}^G, \tilde{u}^0).$$

where $\mathbf{y}^k$ and $\mathbf{x}^k$ denote aggregate production and aggregate demand subsequent to a change from $\tilde{\mathbf{q}}^{k-1}$ to $\tilde{\mathbf{q}}^k$.

Proof. The sequenced valuations given in lines (3.21.2) through (3.21.5) reduce to the valid total measure of benefits (respectively, lines (3.21.1)) by simple algebraic cancellation.

Theorem 3.3 summarizes the general requirements of a valid BC design. The sole distinction between lines (3.21) and the results of the last Chapter is that lines (3.21) provide for a change in profits. Once again, two general approaches are possible. First, as indicated by line (3.21.1), the single one-step valuation of the overall impact is possible. Second, as described by lines (3.21.2) through (3.21.5), it is conceptually possible to decompose the overall policy into its constituent parts and evaluate the impact of each impact separately.

The restrictions of the valid (dis)aggregation design are analogous to those of Chapter II. First, the total valuation obtained by a valid sequenced approach equals the valid aggregate HC measure. Second, to obtain a set of valid component specific valuations, a sequence of valuation is selected and applied. That is, the component impacts, the changes from q_k^0 to q_k^1, are be ordered from first until last and then valued sequentially along a polygonal path that begins at $\mathbf{q}^0$ and ends at $\mathbf{q}^G$. Third, the component valuations are not unique but vary with the particular valuation sequence that is selected. As in the simple case of Chapter 2, had a different sequence of valuation been selected, say, one that reversed the order of component specific changes, a different set of component valuations would have been obtained.

As in Chapter II, the VBC approach has little in common with the IVS. As in the simple case, the IVS evaluates each of the G impacts as if each were a single incremental change in the initial policy vector, $\mathbf{q}^0$. The VBC evaluates each component as a step in a sequence of changes that begins at $\mathbf{q}^0$ and ends at $\mathbf{q}^G$.

Conventional and Valid Benefit Cost Outcomes in the General Case

In this section the comparison of IVS and valid BC outcomes is extended to the general context. As a first step in this extension, the Hicksian compensating measure is analyzed and the results of Theorem 3.1 are shown to hold in a general economic context: as the number of policy components becomes large, the IVS design overstates the benefits of policy change. Since this initial result is due largely to the notion of resource scarcity, the initial large number result is relatively free of auxiliary assumptions. To examine the relative size of aggregate benefits and costs, an additional assumption is made: it is assumed that the marginal costs of policy change are nonzero.

To this point the notion of scarcity has been largely implicit. For instance, the boundedness of feasible production plans limits the feasible quantity of both market and environmental goods. For consumption, such a limitation becomes economically relevant when $\mathbf{X}_i(\mathbf{q},\mathbf{u}_i) \subset \mathbf{R}^+$ and $\mathbf{0} \notin \mathbf{X}_i(\mathbf{q},u_i)$. That is, when a nonnegative quantity of market goods is required in order to sustain an admissible utility level.[7] Because of its importance to the analysis of this section, the restriction on consumption is highlighted with the following definition.

Definition 3.5: Market goods are essential to the initial utility allocation, $\mathbf{u}^0$, if $u_i(\mathbf{0},\mathbf{q}) < u_i^0$ for all $\mathbf{q}$ and some $i \in \{1,\ldots,I\}$.

With these preliminaries, the analysis of a policy agenda can be extended to the general context. Theorem 3.4 generalizes the initial result of Theorem 3.1.

Theorem 3.4: Let the policy environment be epsilon augmentable and let market goods be essential to the initial utility allocation, $\mathbf{u}^0$. Suppose that only components with independent valuations greater than epsilon are considered for implementation. Then if G is the number of policy impacts under consideration, there is an integer N such that for G > N, IVS overstates the valid Hicksian compensating measure associated with the policy agenda.

Proof. The proof differs from that of Theorem 3.1 only in terms of the bound on $hc(\mathbf{q}^G, \mathbf{q}^0)$. Let $\hat{\mathbf{D}}(\mathbf{u}^0) = \{\mathbf{d} \mid \mathbf{d} = \mathbf{x} - \mathbf{y} - \bar{\mathbf{x}} \leq \mathbf{0},\ (\mathbf{y}, \mathbf{q}) \in \hat{\mathbf{W}},\ \mathbf{x} \in \mathbf{X}(\mathbf{u}^0)\}$. $\hat{\mathbf{D}}(\mathbf{u}^0)$ is clearly bounded above. Since $\hat{\mathbf{W}}$ is bounded and $\mathbf{x} > \mathbf{0}$ for all $\mathbf{x} \in \mathbf{X}(\mathbf{u}^0)$, $\hat{\mathbf{D}}(\mathbf{u}^0)$ must be bounded below. Clearly, $\hat{\mathbf{D}}(\mathbf{q}, \mathbf{u}^0)$ is contained in $\hat{\mathbf{D}}(\mathbf{u}^0)$. Since $\hat{\mathbf{D}}(\mathbf{u}^0)$ is bounded, the HC measure identified in Definition 3.2 is bounded for all $\mathbf{q}$.

To extend the analysis to the relative size of benefits and costs, it is assumed that regulatory change is minimally costly.

Definition 3.5: Regulatory change is minimally costly for changes $\mathbf{q}^k$ to $\mathbf{q}^{k-1}$ if (1) there is a firm f for which $\mathbf{q}_{fk}^k > \mathbf{q}_{fk}^{k-1}$ and (2) the marginal cost of the change $\mathbf{q}_{fk}^{k-1}$ to $\mathbf{q}_{fk}^k$ is nontrivial. Marginal cost, MC_{fk}, is nontrivial if there is a $\mu > 0$ such that $MC_{fk} = (\mathbf{D}q_{k-}T_f) / (\mathbf{D}x_{1-}T_f) > \mu$ for all changes from q_{fk}^{k-1} to q_{fk}^{k}.

The final step in the analysis is to demonstrate that, as the number of evaluated impacts becomes large, conventional BC procedures misidentify net loss policies as potential Pareto improvements.

Theorem 3.5: Let the assumptions of Theorem 3.4 hold and suppose that regulatory change is minimally costly. Then there is an integer M such that for G > M, IVS not only (a) overstates the valid Hicksian compensating measure associated with a G impact change but also (b) misidentifies nonPPI alternatives as PPI.

Proof. Theorem 3.4 demonstrates the conclusion (a). To derive (b), conceptually partition an M impact regulatory change, $\mathbf{q}^0$ to $\mathbf{q}^M$, into two stages. Let Stage I encompass (1) the consumption effects of the change from $\mathbf{q}^0$ to $\mathbf{q}^M$ and (2) the regulatory effects on firms with marginal control costs less than or equal to μ. Denote the production controls of Stage I as the change from $\mathbf{q}^0$ to $\hat{\mathbf{q}}^M$. Let Stage II encompass only the regulatory controls on firms with marginal control costs greater than μ. Denote the production controls of Stage II as the change from $\hat{\mathbf{q}}^M$ to $\mathbf{q}^M$.

The feasible aggregate demands resulting from Stage I are defined by

$$(3.22) \qquad \hat{\mathbf{D}}(\hat{\mathbf{q}},\mathbf{u}) = \{\mathbf{d} \mid \mathbf{d} = \mathbf{x} - \mathbf{y} - \bar{\mathbf{x}} \leq \mathbf{0},\ \mathbf{x} \in X(\mathbf{q}^M,\mathbf{u}^0),\ \mathbf{y} \in Y(\hat{\mathbf{q}}^M),\ \mathbf{q} = \mathbf{g}(\mathbf{q}^M)\}.$$

and $\hat{\mathbf{D}}(\hat{\mathbf{q}}^M,\mathbf{u})$ is assumed to be nonempty. Let $h\hat{c}^M$ measure the benefits of Stage I:

$$(3.23) \qquad \mathbf{0} \leq \mathbf{d} + \mathbf{h}\hat{c}^M$$

for all $\mathbf{d} \in \hat{\mathbf{D}}(\hat{\breve{\mathbf{q}}}^M, \breve{u}^0)$ and the strict equality holds for at least one $\mathbf{d} \in \hat{\mathbf{D}}(\hat{\breve{\mathbf{q}}}^M, \breve{u}^0)$. For all $\hat{\breve{\mathbf{q}}}^M$, $\hat{hc}^M$ is bounded (see Theorem 3.4). Let $\bar{a} = \sup \hat{hc}^M(\hat{\breve{\mathbf{q}}}^M, \breve{\mathbf{q}}^0)$ for all $\hat{\breve{\mathbf{q}}}^M$, $M \in \{1,\ldots,K\}$.

The aggregate demands resulting from Stage II are defined by

$$(3.24) \qquad \mathbf{D}(\breve{\mathbf{q}}, \breve{u}) = \{\mathbf{d} \mid \mathbf{d} = \mathbf{x} - \mathbf{y} - \bar{\mathbf{x}},\ \mathbf{x} \in \mathbf{X}(\breve{\mathbf{q}}^M, \breve{u}^0),\ \mathbf{y} \in \mathbf{Y}(\breve{\mathbf{q}}^M),\ \mathbf{q} = \mathbf{g}(\breve{\mathbf{q}}^M)\}.$$

The Hicksian compensating measure for Stage II is hc^M,

$$(3.25) \qquad \mathbf{0} \leq \mathbf{d} + \hat{\mathbf{hc}}^M + \mathbf{hc}^M$$

for all $\mathbf{d} \in \mathbf{D}(\breve{\mathbf{q}}^M, \breve{u}^0)$ and the equality holds for at least one $\mathbf{d} \in \mathbf{D}(\breve{\mathbf{q}}^M, \breve{u}^0)$. For the overall change from $\breve{\mathbf{q}}^0$ to $\breve{\mathbf{q}}^M$, the Hicksian compensating measure is $\hat{hc}^M + hc^M$.

Let $\hat{\mathbf{x}}^M$, $\hat{\mathbf{y}}^M$, and $\hat{\mathbf{p}}^M$ denote, respectively, aggregate demand, aggregate supply, and the price vector associated with the compensated equilibrium at $\hat{\mathbf{q}}^M$. Let $\mathbf{x}^M$ and $\mathbf{y}^M$ denote, respectively, aggregate demand and aggregate supply associated with the compensated equilibrium at $\breve{\mathbf{q}}^M$. By the convexity of preferences,

$$(3.26) \qquad \hat{\mathbf{p}}^M(\mathbf{x}^M - \hat{\mathbf{x}}^M) \geq 0.$$

Substituting $\hat{\mathbf{x}}^M = \hat{\mathbf{y}}^M + \bar{\mathbf{x}} + \hat{\mathbf{hc}}^M$ and $\mathbf{x}^M = \mathbf{y}^M + \bar{\mathbf{x}} + \hat{\mathbf{hc}}^M + \mathbf{hc}^M$,

$$(3.27) \qquad \hat{\mathbf{p}}^M(\mathbf{y}^M - \hat{\mathbf{y}}^M) \geq hc^M.$$

By assumption, for each component change from q_k^{k-1} to q_k^k encompassed by the Stage II change from $\hat{\mathbf{q}}^M$ to $\mathbf{q}^M$, there is at least one firm which experiences positive marginal costs. By the convexity of $T_f(\cdot)$ and by the assumption of profit maximization, the costs of the change from q_k^{k-1} to q_k^k are such that

$$(3.28) \qquad \hat{\mathbf{p}}^M(y_f^M - \hat{y}_f^M) \leq -MC_{fk}(q_{fk}^k - q_{fk}^{k-1}).$$

With $MC_{fk} > 0$ and $q_{fk}^k - q_{fk}^{k-1}$ finite, there is a $\sigma > 0$ such that $MC_{fk}(q_{fk}^k - q_{fk}^{k\ 1}) > \sigma$ for all f and k. Adding (3.28) across all firms

$$(3.29) \qquad \hat{\mathbf{p}}^M(\mathbf{y}^M - \hat{\mathbf{y}}^M) \leq -M\sigma$$

where the right hand side of (3.29) follows from the assumption that each of the M components is minimally costly. Using (3.27) and (3.29),

$$(3.30) \qquad -M\sigma \geq hc^M.$$

Let $M \geq \bar{a}/\sigma$. Then for a G impact policy, $G > M$, the valid total Hicksian measure is $\hat{hc}^G + hc^G < 0$. The IVS valuation, however, remains strictly positive and increasing in G.

Summary and Conclusions

Results of this Chapter round out and extend the analysis of conventional and valid BC designs. The last Chapter left the analysis with a question. Though conventional procedures were shown to induce routine error into BC outcomes, it was not clear whether such error might cancel out as the number of evaluated components becomes large. Left open was the possibility that conventional BC outcomes might, on average, approximate the outcomes of a valid BC design.

The results of this Chapter rule out conventional procedures as an approximately valid approach even as the number of evaluated components becomes large. To demonstrate the systematic error in conventional procedures, Theorem 3.1 operationalizes two basic concepts. First, Theorem 3.1 asserts that there are a large number of policy alternatives that appear beneficial when evaluated as the proximate incremental program to an existing set of baseline conditions--that is, when evaluated by conventional procedures. Second, Theorem 3.1 introduces economic scarcity and demonstrates that a budget-like resource constraint bounds the valid net benefit measure. By combining these two concepts, conventional procedures are shown to systematically overstate the net benefits of policy change.

Left unresolved by Theorem 3.1 was whether conventional procedures actually misstate the sign of a valid benefit cost outcome. To address this question, additional specification of the economy was required. Therefore, the second section of this Chapter described the analytical properties of aggregate demand and supply and detailed a generalized form of the HC net benefit measure. The general HC measure was composed of (1) the change in resource rents plus (2) the change in aggregate profit share minus (3) the change in minimum expenditure required to maintain initial utility. In the third section, the HC measure was used to derive general forms of both the conventional and valid BC designs. Notably, the restrictions of this more inclusive valid design were virtually identical to those discussed in Chapter II. Once again, conventional procedures were shown to ignore the constraints of a valid design.

With the structure of the economy explicit, a fourth section examines both the size and sign of conventional benefit cost outcomes. First, under conditions analogous to Theorem 3.1, Theorem 3.3 shows that, in a general setting, conventional procedures systematically overstate valid benefit cost outcomes. With this initial result clear, an additional restriction is added. It is asserted that policy change is minimally costly--that the marginal costs of component change are positive. Theorem 3.4 combines the notion of minimal policy costs with the prior two assertions of scarcity and the desirability of at least the first incremental change. A valid measure of benefits is shown once again to be bounded. The aggregate costs of policy change, however, are shown to be strictly increasing and unbounded. Thus, as the number of evaluated components becomes large, the valid measure of net benefits becomes negative. The conventional measure once again fails to account for the bound on benefits and remains strictly increasing, positive, and unbounded. Thus, as the number of evaluated components becomes large, conventional procedures not only systematically overstate net benefits but also misstate the sign of a valid BC outcome.

Overall, then, conventional procedures fail to approximate a valid benefit cost outcome as the number of policy components becomes large. Given economic scarcity and the desirability of a large number of policy components when each is evaluated as the first marginal policy component, conventional procedures systematically overstate the valid BC outcome. If, in addition, the marginal resource costs of component policy change are positive, conventional procedures also misstate the sign of a valid BC outcome and thereby misidentify net loss policy alternatives as potential Pareto improvements.

Endnotes

1. For a discussion of compensated equilibria, see Arrow and Hahn.
2. Insofar as both N and G are finite, the theorem is somewhat stronger than the asymptotic results common to econometric analysis. Chung gives an technical overview of various types of convergence.
3. This is not the Scitovsky paradox [Scitovshy]. To see this, recall that the Scitovsky paradox is obviated by compensation [Quirk and Saposnik]. Because the IVS tends to overstate compensation, the instability or reversal phenomena suggested above is likely to be exacerbated by actual compensation.
4. The analysis of aggregate consumption, production, and excess demand generally follows the notation of Arrow and Hahn.
5. The assumption of scarcity in these terms is typical of general equilibrium models.
6. For a detailed proof of compactness under similar conditions, see Arrow and Hahn, pp. 66-67.
7. See Arrow and Hahn, pp. 89.
8. In this case a household's indirect utility function is

$$v_i(\mathbf{p},\mathbf{q}) = \{u_i \mid u_i = \max_{\mathbf{x}_i} u_i(\mathbf{x}_i,\mathbf{q}) \text{ s.t. } \mathbf{p}\mathbf{x}_i = \mathbf{p}\bar{\mathbf{x}}_i + t_i\mathbf{p}\mathbf{y}\}$$

for all $i \in \{1,\ldots,I\}$

9. See the general proof for an economy with externalities in Arrow and Hahn.

Appendix 3A

Proof of Theorem 3.2

Proof. If hc > 0 then the change from $\tilde{q}^0$ to $\tilde{q}$ is clearly a PPI. On the other hand, $\hat{D}(\tilde{q},\tilde{u}^0)$ is compact so an hc can be found such that

$$(3.18) \qquad d_1 + hc = x_1 - y_1 - \bar{x}_1 \geq 0 \quad \text{for all } d \in \hat{D}(\tilde{q},\tilde{u}^0)$$

and the equality holds for at least one $\mathbf{d}^* \in \mathbf{D}(\tilde{q},\tilde{u}^0)$. Since $\mathbf{d}^* \in \hat{D}(\tilde{q},\tilde{u}^0)$, we know that

$$(3.19) \qquad d_j^* = x_j^* - y_j^* - \bar{x}_j \leq 0 \quad \text{all } j \neq 1.$$

Suppose that the strict inequality holds for some j. Since u_i and T_f are strictly monotonic and continuous, one can find $x_j' > x_j^*$ and $x_1' < x_1^*$ or $-y_j' > -y_j^*$ and $-y_1' < -y_1^*$ such that

$$(3.20) \qquad d_j' = x_j' - y_j' - \bar{x}_j < 0,$$

$u_i(\mathbf{x}_i^*,\mathbf{q}) = u_i(\mathbf{x}_i',\mathbf{q})$ or $T_f(\mathbf{y}_f',\tilde{\mathbf{q}}_f) = 0$ and $\mathbf{d}' < 0$. Then, $\mathbf{d}' \in \mathbf{D}(\tilde{q},\tilde{u}^0)$ and

$$(3.21) \qquad d' = x_1' - y_1' - \bar{x}_1 + hc < 0.$$

But line (3.11) contradicts the assumption on hc.

Finally, suppose $\tilde{u}^0$ is Pareto efficient for both hc′ and hc″. Suppose hc′ > hc″. By assumption, $\mathbf{d} + \mathbf{hc}' \geq \mathbf{0}$ for all $\mathbf{d} \in \mathbf{D}(\tilde{q},\tilde{u}^0)$ and $\mathbf{d} + \mathbf{hc}' = \mathbf{0}$

for at least one $\mathbf{d}^0 \in \hat{\mathbf{D}}(\tilde{\mathbf{q}},\tilde{\mathbf{u}}^0)$. But then $\mathbf{d}^0 + \mathbf{hc}'' < 0$, contradicting that $\tilde{\mathbf{u}}^0$ is Pareto efficient at $\mathbf{hc}''$. ◇

Chapter IV

VALUING ENVIRONMENTAL IMPACTS WITH THE VALID DESIGN

The valid BC framework suggests two general approaches to improving the BC evaluation of policy. First, the valid framework can be used as a guide in the design of specific BC studies. For a given set of baseline conditions, evaluation may proceed by either the one-step, holistic approach or the sequenced approach discussed in Chapter II and III. Second, the framework can be used to guide the design of an analytical system that is adaptable to changing baseline conditions.

An adaptable specification of the general BC design would require a specification of net supply, **y**, a specification of demands, **x**, and sufficient information to estimate system parameters. Though complex, several components of the model are well established in the literature. For instance, a broad range of alternatives exist for the specification of market demand systems [see Christensen, Jorgenson, and Lau; Deaton and Muellbauer (1980b)]. Methods for computing the Hicksian measures with respect to market price and quantity changes are also well established [see Willig (1976, 1979); Bergland and Randall]. Finally, computational methods for applied general equilibrium analysis are readily accessible [Shoven and Whalley]. Absent from the general literature, however, are empirical specifications that encompass the direct impacts of environmental change.

The objective of this Chapter is to work toward an estimable specification of the environmental portion of the valid design. The immediate objective is to develop a system of equations that can be used to adapt environmental benefits and cost data to changing baseline conditions and shifting policy objectives. Over the longer term, a well developed model of the environmental sector may provide the cornerstone for a more complete analytical system that would include environmental impacts, market prices, and market quantities.

The Chapter is organized in the following way. The first section outlines a general approach to specification of the environmental portion of the valid design. The second and third sections implement this specification process in terms of two different functional forms. The fourth section uses available benefit cost data to simulate the change in benefit cost outcomes under various substitution scenarios.

An Approach to Empirical Specification

The valid BC design describes a functional relationship between environmental parameters, market prices, and the HC measure. With $\mathbf{q} \in \mathbf{R}^K$ and $\mathbf{p} \in \mathbf{R}^J$, the relationship is abstractly described as a function $hc:\mathbf{R}^{K+J} \rightarrow \mathbf{R}$. The objective of this Chapter is to specify the environmental interactions encompassed by hc in terms of estimable functional forms. The specification process has three steps.

The first step is to characterize a function $hc':\mathbf{R}^K \rightarrow \mathbf{R}$ in a manner consistent with the valid design. To accomplish this, line (2.14.1) is rewritten as

$$(4.1.1) \quad hc_i(\mathbf{q}^G,\mathbf{q}^0) = m_i^0 - e(\mathbf{p}^0,\mathbf{q}^G,u_i^0)$$

$$(4.1.2) \quad + (\mathbf{p}^G - \mathbf{p}^0)\bar{\mathbf{x}}_i - [e_i(\mathbf{p}^G,\mathbf{q}^0,u_i^0) - e(\mathbf{p}^0,\mathbf{q}^G,u_i^0)]$$

Line (4.1) partitions the valid BC design into two stages. The first stage is given by the righthand side of line (4.1.1) and evaluates environmental impacts at constant initial prices. The second stage is line (4.1.2) and evaluates price impacts given the post policy level of environmental parameters. The righthand side of (4.1.1) includes only the direct environmental impacts of policy and can be viewed as a first stage in implementing the valid design. Therefore, hc′ is defined as

$$(4.2) \qquad hc'_i(\mathbf{q}^G,\mathbf{q}^0) = m_i^0 - e(\mathbf{p}^0,\mathbf{q}^G,u_i^0).$$

To simplify notation, the subscript i is suppressed and the initial price vector is denoted as **p**. Thus, line (4.2) can be rewritten as

$$(4.3) \qquad hc'(\mathbf{q}^G,\mathbf{q}^0) = m^0 - e(\mathbf{p},\mathbf{q}^G,u^0).$$

The second step in specification varies with the type of information that is available for estimation. Hoehn identifies two possible estimation approaches. First, line (4.3) is directly applicable as a structural model for the total value data obtained in contingent valuation [Randall, Ives, and Eastman; Brookshire, Ives, and Schulze] or from previous studies such as Freeman (1982) and Public Interest Economics. Second, it may sometimes be possible to use the weak complementarity approach [Mäler] to state environmental valuations in terms of the compensated demands for market goods. Using this latter approach, line (4.3) would be rewritten

$$(4.4) \qquad hc'(\mathbf{q}^G,\mathbf{q}^0) = \int_{\mathbf{p}^0}^{\mathbf{p}^*} [\mathbf{x}(\mathbf{p},\mathbf{q}^G,u^0) - \mathbf{x}(\mathbf{p},\mathbf{q}^0,u^0)]d\mathbf{p}$$

In this Chapter, the total value approach is taken.

The third step in specification is to state the expenditure function of line (4.3) in terms of a specific functional form. The next two sections state the total value structure, line (4.3), in terms of two functional forms: (1) a Cobb-Douglas (CD) form and (2) a second order Taylor series approximation (TSA). The CD form provides a straightforward framework for comparing the valid and conventional designs. Though relatively simple to estimate, the CD approach is restrictive in the degree of substitution that it allows. The TSA follows a now standard avenue to the derivation of flexible functional forms [Gallant (1978)]. Such forms are flexible in that they impose relatively few a priori restrictions on the estimation of system parameters. Both the CD and TSA forms are used (1) to identify the relevant substitution parameters between environmental parameters and (2) to assess the feasibility of alternative estimation techniques.

The Cobb-Douglas Form

The specification of line (4.3) in terms of the CD form begins with the indirect utility function,

$$(4.4.1) \quad v(\mathbf{p},\mathbf{q},m) = C\mathbf{p}^{\mathbf{a}}\mathbf{q}^{-\mathbf{b}}m$$

$$(4.4.2) \quad = B\mathbf{q}^{-\mathbf{b}}m$$

where C is a constant, $C\mathbf{p}^{\mathbf{a}} = B$, $\mathbf{q}^{-\mathbf{b}} = \prod_{k=1}^{K} q_k^{(-b_k)}$, and $b_k < 0$. The signs of the exponents imply that a price increase reduces utility while an increase in environmental quality increases utility.

By inverting equation (4.4), the expenditure function can be obtained. Accordingly,

$$(4.5.1) \quad e(\mathbf{p},\mathbf{q},u) = C^{-1}\mathbf{p}^{-\mathbf{a}}(\mathbf{q})^{\mathbf{b}}u$$

$$(4.5.2) \quad = D\mathbf{q}^{\mathbf{b}}u$$

where D = 1/B. By the sign of the exponents, an increase in prices increases the minimum amount of income required to maintain utility constant. An increase in environmental quality, however, reduces the minimum amount of expenditure required to maintain utility constant.

To state the expenditure function in a form composed of observable parameters alone, $u^0 = B(\mathbf{q}^0)^{-\mathbf{b}}m^0$ is substituted into line (4.5.2) to obtain

$$(4.6.1) \quad e(\mathbf{p},\mathbf{q}^1,u^0) = e(\mathbf{p},\mathbf{q}^1,\mathbf{q}^0,m^0)$$

$$(4.6.2) \quad = \prod_{k=1}^{K} (q_k^0/q_k^1)^{(-b_k)}m^0$$

where $\mathbf{q}^0$ denotes the initial and $\mathbf{q}^1$ the post policy level of environmental parameters.

Using equations (4.5) and (4.6) the Hicksian compensating measure for a single impact policy that changes q_k^0 to q_k^1 is

$$(4.7.1) \quad hc'(q_k^1,q_k^0,u^0) = m^0 - e(\mathbf{p},q_1^0,\ldots,q_k^1,\ldots,q_K^0,u^0)$$

$$(4.7.2) \quad = m^0 - (q_k^0/q_k^1)^{(-b_k)}m^0.$$

Line (4.7) illustrates two points regarding the CD form of the single impact valuation. First, only two environmental parameters enter into the CD structure of the independent valuation: (1) the initial level of environmental quality and (2) the post-policy level of environmental quality for the specific impact under evaluation. Second, given the initial and post-policy levels of environmental quality, only two individual characteristics determine the benefit outcome: disposable income, m^0, and the exponent b_k. Ceteris paribus, CD benefit measures increase or decrease (in absolute value) with an increase or a decrease in disposable income.

Both the conventional and valid BC designs can be stated in the CD form. Using equation (4.7.1), the conventional measure of environmental benefit or costs

$$(4.8.1) \quad ivs = \sum_{k=1}^{K} hc'(q_k^1, q_k^0, u^0)$$

$$(4.8.2) \quad = \sum_{k=1}^{K} [1 - (q_k^0/q_k^1)^{(-b_k)}]m^0$$

Using equations (4.3) and (4.6.2), however, the valid environmental benefit measure is

$$(4.9.1) \quad hc'(\mathbf{q}^1, \mathbf{q}^0, u^0) = m^0[1 - \prod_{k=1}^{K} (q_k^0/q_k^1)^{(-b_k)}]$$

$$(4.9.2) \quad = m^0[1 - (q_1^0/q_1^1)^{(-b_1)}] + \ldots$$

$$(4.9.3) \quad + \; m^0[1 - (q_k^0/q_k^1)^{(-b_k)}] \prod_{j=1}^{k-1} (q_j^0/q_j^1)^{(-b_j)} + \ldots$$

$$(4.9.4) \qquad + \; m^0[1 - (q_K^0/q_K^1)^{(-b_K)}] \prod_{j=1}^{K-1} (q_j^0/q_j^1)^{(-b_j)}.$$

The bracketed quantities in lines (4.9.2) through (4.9.4) are the single impact, component-specific benefit measures. Equation (4.9) can be rewritten as

$$(4.10.1) \quad hc'(\mathbf{q}^1,\mathbf{q}^0,u^0) \;=\; hc'(q_1^1,q_1^0,u^0) + \ldots$$

$$(4.10.2) \qquad + \; [hc'(q_k^1,q_k^0,u^0)] \prod_{j=1}^{k-1} (q_j^0/q_j^1)^{(-b_j)} + \ldots$$

$$(4.10.3) \qquad + \; [hc'(q_K,q_K^0,u^0)] \prod_{j=1}^{K-1} (q_j^0/q_j^1)^{(-b_j)}.$$

A comparison of lines (4.8.1) and (4.8.2) with lines (4.10.1) through (4.10.3) leads to several observations. First, as argued previously, the conventional approach ignores the global impact of policy and evaluates each impact as if it were an independent, single impact policy. Second, with the CD form, the single impact benefit measures are fundamental to both the conventional and valid approaches. However, as shown in lines (4.10.1) through (4.10.3), at each step of the valid sequenced valuation each of the single impact valuations is reduced by a specific proportion--the proportion by which previously valued impacts have reduced the minimum expenditure required to maintain u^0. For instance, consider the valuation of the change from q_k^0 to q_k^1. Previously sequenced changes in environmental quality reduce the minimum expenditure required to maintain u^0 to

$$(4.11) \quad e(\mathbf{p},q_1^1,\ldots,q_{k-1}^1,q_k^0,q_{k+1}^0,\ldots q_K^0,u^0) \;=\; m^0 \prod_{j=1}^{k-1} (q_j^0/q_j^1)^{(-b_k)}.$$

As shown in both lines (4.9.3) and (4.10.2), the evaluation of q_k^1--after the k-1 prior changes--results in the single impact valuation, $HC(q_k^1,q_k^0,u^0)$, multiplied by a proportion

$$(4.12)\quad \prod_{j=1}^{k-1} (q_j^0/q_j^1)^{(-b_k)}.$$

A third point to be drawn from a comparison of equation (4.9) and (4.10) is that, in the CD form, environmental parameters are strictly competitive. An increase in, say, q_1, reduces the benefit of an improvement in q_2. Consider a two-part policy with the impact on q_1 evaluated first. The respective sequenced valuation of the change in q_1^0 is given in line (4.10). The sequenced valuation of the change in q_2 from q_2^0 to q_2^1 is

$$(4.13)\quad e(\mathbf{p},q_1^1,q_2^0,u^0) - e(\mathbf{p},q_1^1,q_2^1,u^0) = [hc'(q_2^1,q_2^0,u^0)](q_1^0/q_1^1)^{(-b_1)}.$$

Because $q_1^1 > q_1^0$, $(q_1^0/q_1^1)^{(-b_1)} < 1$ and an increase in one quality level reduces the benefit of a subsequent change in another environmental quality level. With the CD form, then, environmental parameters are uniformly competitive.

As a final point of comparison, note that both the conventional and sequenced approaches contain exactly the same parameters when expressed in the CD form. Therefore, given the information contained in a specific set of independent or sequenced valuations, the exponents b_k and even m^0 are potentially estimable. Once the b_k and m^0 are estimated from an appropriate subset of benefit data, valid benefit measures are estimable for an arbitrary valuation sequence;

one must simply decide upon the sequence of valuation and then arrange the component valuations accordingly by using the estimated CD structure.

An Estimable Cobb-Douglas Form

The CD form of the expenditure function identifies a set of parameters that, by assumption, underlie both the conventional and valid BC designs. In this section, an approach for estimating the CD parameters is suggested. At this initial stage of investigation, only one of several estimation alternatives is considered--that of estimating the exponents b_k upon a set of independent valuations obtained in contingent valuation.

The basic data set considered is a sample of independent valuations. The sample of contingent valuation data is composed of the independent valuations, the respective initial and post-policy levels of environmental quality, and individual levels of discretionary income. Formally, the sample is a collection of ordered four-tuples,

$$(4.14) \qquad \{(hc'^{1}_{kh}, q^{1}_{kh}, q^{0}_{kh}, m^{0}_{h})\}$$

where m^0_h is the discretionary income of the hth individual ($h \in \{1,\ldots,H\}$), q^0_{kh} is the initial level of the kth environmental quality parameter as experienced by the hth individual, q^l_{kh} is a similarly defined quantity for the lth post-policy level of environmental quality, and hc'^{l}_{kh} the independent valuation of the environmental change from q^0_{kh} to q^l_{kh},

$$(4.15) \qquad hc'^{l}_{kh} = hc'(q^{l}_{kh}, q^{0}_{kh}, u^{0}_{h})$$

With the CD form,

$$(4.16)\quad hc'^{1}_{kh} = m^{0}_{h} - (q^{0}_{kh}/q^{1}_{kh})^{(-b_k)}\exp(a_k + u_{hk})m^{0}_{h}$$

where $a_k + u_{hk}$ is a stochastic structure (a_k is a constant) that accounts for factors not directly measured or observed. By rearranging and taking logs, we get

$$(4.17)\quad y^{1}_{kh} = a_k - b_k \ln(q^{0}_{kh}/q^{1}_{kh}) + u^{1}_{hk}$$

where $y^{1}_{kh} = \ln[(m^{0}_{h} - hc'^{1}_{kh})/m^{0}_{h}]$ is the log of the ratio of the expenditure function, $e(\mathbf{p}, q^{1}_{kh}, u^{0})$, to initial income.

The CD form yields a simple linear equation with which the b_k can be estimated. If the distributional characteristics of u_{kh} meet the requirements of ordinary least squares (OLS), a simple regression of y^{1}_{kh} on $\ln(q^{0}_{kh}/q^{1}_{kh})$ could be used to estimate b_k.

One approach that satisfies the OLS requirements is to draw a random sample of individuals from the population potentially affected by policy. Each of the sampled individuals would be presented with <u>one</u> post-policy alternative and a single independent valuation, hc'^{1}_{kh}, would be elicited. Additional questions would be required to measure discretionary income, m^{0}_{h}. With each individual asked a single valuation question for a single level of environmental quality little correlation between error terms would be expected. The covariance matrix would therefore be

$$(4.18)\quad E[\mathbf{uu}'] = s^{2}\mathbf{I}$$

where s^2 is a constant and **I** is an identity matrix. With this fully random sampling design, the distribution of **u** satisfies the OLS requirements.[3]

Having estimated a set of b_k any arbitrary set of sequenced valuations can be obtained from the independent valuations. For instance, suppose that a multi-part policy affects only q_1^0 and q_2^0 and, by the procedure described above, the estimates $\hat{b}_1$ and $\hat{b}_2$ are obtained. If the anticipated sequence of implementation changes q_1^0 to q_1^1, first, and q_2^0 to q_2^1, second, then the appropriate valuation of the change in q_1^0 is hc'^{1}_{kh}. For the second environmental parameter, the valid, sequenced CD valuation is

$$(4.19) \qquad hc'[(q_{1h}^1, q_{2h}^1), (q_{1h}^1, q_{2h}^0), u^0] \;=\; (hc'^{1}_{2h})(q_{1h}^0/q_{1h}^1)^{(-\hat{b}_1)} m_h^0$$

Similarly, if the valuation sequence were reversed, the appropriate valuation of the change in q_1^0 would be

$$(4.20) \qquad hc'[(q_{1h}^1, q_{2h}^1), (q_{1h}^0, q_{2h}^1), u_h^0] \;=\; (hc'^{1}_{1h})(q_{2h}^0/q_{2h}^1)^{(-\hat{b}_2)} m_h^0$$

A typical environmental policy is likely to affect more than two environmental parameters. However, in the multi-parameter case, the CD approach would be analogous to the procedure described above: (1) estimate the b_k upon a set of independent valuations and (2) transform the independent valuations using the CD form of the valid BC design given in equation (4.9).

An Approach by Taylor Series Approximation

The CD approach illustrates one structure that may underlie the total and component valuations. However, the CD form is restrictive. For instance, the restrictions of homotheticity, unitary elasticity of substitution, and resulting constant expenditure elasticities are well known. Moreover, while these restrictions obviously reduce the data required for estimation, it is by no means clear that the CD approach makes full use of all the information contained in a given set of data.

To sidestep the restrictions of the CD form, a Taylor series approximation (TSA) to the general form of the valid BC design, equation (4.3), is derived. With this general TSA model, expenditure elasticities are free to vary and both competitive and complementary relations are permitted among environmental parameters. Not surprisingly, the most general and flexible form of the TSA model requires substantial data for estimation. To relax these data requirements, three alternative forms nested within the general TSA are examined.

Before deriving the general TSA, the notation used with the CD form is respecified. Overall, the derivation focuses on three sets of parameters that may vary across individuals: (1) the pre-policy or initial level of environmental quality, $\mathbf{q}_h^0$; (2) the post-policy level of environmental quality, $\mathbf{q}_h$; and (3) discretionary income, m_h^0. A specific level, $l \in \{1,\ldots,L\}$, of post-policy environmental quality is indicated by q_h^l. Since both $\mathbf{q}_h^0$ and $\mathbf{q}_h^l$ play a structurally similar role in the TSA approach, we let $\mathbf{z}_{kh}^l = (q_{kh}^0, q_{kh}^l)$. The vector of initial and post-policy levels of environmental quality can therefore be represented as $\mathbf{z}_h^l = (\mathbf{z}_{1h}^l,\ldots,\mathbf{z}_{Kh}^l)$. Three additional points are also important:

i. To derive the elasticity form of the TSA, the variables Q_{kh}^0, Q_{kh}^l, $\mathbf{Q}_h^0$, $\mathbf{Q}_h^l$,, Z_{kh}^l, $\mathbf{Z}_h^l$, M_h^0, and $\mathbf{N}_h^l$ are defined as $Q_{kh}^0 = \ln q_{kh}^0$, $Q_{kh}^l = \ln q_{kh}^l$, $\mathbf{Q}_h^0 = (\ln q_{1h}^0,\ldots,\ln q_{kh}^0,\ldots,\ln q_{Kh}^0)$, $\mathbf{Q}_h^l = (\ln q_{1h}^l,\ldots,\ln q_{kh}^l,\ldots,\ln q_{kh}^l)$,

$Z^1_{kh} = (Q^0_{kh}, Q^1_{kh})$, $\mathbf{Z}^1_h = (Z^1_{1h}, \ldots, Z^1_{kh}, \ldots, Z^1_{Kh})$, $M^0_h = \ln m^0_h$, and $\mathbf{N}^1_h = (Z^1_h, M^0_h)$.

ii. To simplify the notation for the derivative operator, we let $\mathbf{D}_k \ln e$ denote the derivative of $\ln e(\cdot)$ with respect to $\mathbf{Z}_k$, $\mathbf{D}_M \ln e$ denote the derivative of $\ln e(\cdot)$ with respect to M, and $\mathbf{D}_\mathbf{N} \ln e$ denote the derivative of $\ln e(\cdot)$ with respect to N.

iii. Mean values are represented with a bar: The mean of Q_{kh} across h is $\bar{Q} = (1/H) \sum_{h=1}^{H} \ln q_{kh}$. With this notation, $\bar{\mathbf{z}}^0_k = (\bar{Q}^0_k, \bar{Q}^0_k)$.

The objective of the TSA approach is to derive a general approximation to the valuation equation,[3]

$$(4.20) \qquad hc' = m^0 - e(\mathbf{q}^1, u^0).$$

Because the intention is to derive the elasticity form of the approximation and because some individuals may have zero valuations for certain post-policy situations, the equation for HC is rearranged to obtain

$$(4.21) \qquad m^0 - hc' = e(\mathbf{q}^1, u^0).$$

Substituting $v(\mathbf{p}, \mathbf{q}^0, u^0)$ for u^0 and suppressing the notation $v(\mathbf{p}, \cdot)$ yields an expenditure function identified entirely in terms of observable variables. Adding subscripts $h \in \{1, \ldots, H\}$ to allow for variation in $\mathbf{q}^0_h$, $\mathbf{q}^1_h$, and m^0_h across households and taking the natural log of both sides of equation (4.21) yields

$$(4.22) \quad \ln(m_h^0 - hc_h') = \ln e(\mathbf{q}_h^0, \mathbf{q}_h^1, m_h^0)$$

$$= \ln e(z_h^1, m_h^0).$$

Taking a second order Taylor series approximation to equation (4.22) results in

$$(4.23) \quad \ln(m_h^0 - hc_h') = \ln e(z_h^1, m_h^0) + (dZ_h^1, dM_h)(\mathbf{D_N}\ln e)$$

$$+ (1/2)(dZ_h^1, dM_h)'[\mathbf{D_{NN}}\ln e](dZ_h^1, dM_h) + u_{kh}$$

where $dZ_h^1 = (Z_h^1 - \bar{Z}^0)$, $dM_h = (M_h^1 - \bar{M}^0)$, u_{kh} is an error component due to higher order terms, and $e(z^1, m^0)$, $\mathbf{D_N}\ln e$, and $\mathbf{D_{NN}}\ln e$ are each evaluated at the mean of the initial values of N_h^0. Table 4.1 shows that $\mathbf{D_N}\ln e$ and $\mathbf{D_{NN}}\ln e$ are simply the gradient and Jacobian, respectively, of $\ln e(\cdot)$. The economic and functional properties of $e(\cdot)$ imply that $\mathbf{D_N}\ln e < 0$ and that $\mathbf{D_{NN}}\ln e$ is symmetric and non-negative definite.

In considering equation (4.23) as a tool for generalizing a set of value data, three points are important. First, the TSA approximation is a "parsimonious flexible form" [Fuss, McFadden, and Mundlak]. Parsimonious implies that the (2k+2)(2k+3)/2 parameters of the TSA are necessary and sufficient to identify or compute all the elasticity and share parameters that fully characterize an expenditure function. Flexible implies that, at a particular point, the TSA approximates any given set of expenditure relations that may underlie a set of value data.

Table 4.1. The TSA Parameters

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i. $$\mathbf{b} = \mathbf{D_N}\ln e = \begin{vmatrix} D_1 \ln e \\ \vdots \\ D_k \ln e \\ \vdots \\ D_K \ln e \end{vmatrix} \text{ is } (2K+1)X1$$

ii. $$\mathbf{B} = \mathbf{D_{NN}}\ln e = \begin{vmatrix} \mathbf{D_{ZZ}}\ln e & \mathbf{D_{ZM}}\ln e \\ \mathbf{D_{MZ}}\ln e & \mathbf{D_{MM}}\ln e \end{vmatrix} \text{ is } (2K+1)(2K+1)$$

iii. $$\mathbf{D_{ZZ}}\ln e = \begin{vmatrix} D_{11}\ln e & \dots & D_{1k}\ln e & \dots & D_{1K}\ln e \\ \vdots & & \vdots & & \vdots \\ D_{k1}\ln e & \dots & D_{kk}\ln e & \dots & D_{kK}\ln e \\ \vdots & & \vdots & & \vdots \\ D_{K1}\ln e & \dots & D_{Kk}\ln e & \dots & D_{KK}\ln e \end{vmatrix} \text{ is 2KX2K and symmetric}$$

iv. $$\mathbf{D_{MZ}}\ln e = \begin{vmatrix} D_{M1}\ln e & \dots & D_{Mk}\ln e & \dots & D_{MK}\ln e \end{vmatrix} \text{ is } (2K+1)X1$$

v. $$\mathbf{D_{kk}}\ln e = \begin{vmatrix} D_{QQ}\ln e & D_{Q(Q^0)}\ln e \\ D_{(Q^0)Q}\ln e & D_{(Q^0)(Q^0)}\ln e \end{vmatrix} \text{ is 2X2}$$

In addition to being parsimonious and flexible, the TSA is also estimable. The overall form is quadratic and linear in the parameters **b** and **B** (Table 4.1). Therefore, given sufficient data on $hc_h'^1$, m_h^0, and $\mathbf{z}_h^1$, both **b** and **B** are estimable using widely available linear econometric techniques. If a problem arises in estimation, it will most likely involve a trade-off between data availability and the (2k+2)(2k+3)/2 parameters implied by flexibility.

Finally, the interpretation of TSA parameters is direct. Let $\hat{\mathbf{b}} = (\hat{b}_i)$ and $\hat{\mathbf{B}} = [\hat{B}_{ij}]$ be, respectively, the estimated parameters **b** and **B**. The estimated functional form and predicted log of the expenditure level are

$$(4.24) \qquad \ln e(\mathbf{z}_h^1, m_h^0) \;=\; \bar{M}^0 \;+\; (d\mathbf{Z}_h^1, dM_h)\hat{\mathbf{b}} \;+\; (1/2)(d\mathbf{Z}_h^1, dM_h)\hat{\mathbf{B}}(d\mathbf{Z}_h^1, dM_h^1).$$

The elasticity of expenditure with respect to a change in Q_{kh} is, by differentiation of equation (4.24),

$$(4.25) \qquad \hat{c}_{ih}^1 \;=\; \hat{b}_i \;+\; (d\mathbf{Z}_h^1, dM_h^1)\hat{\mathbf{B}}_{i-}$$

where $i \in \{1,\ldots,2K\}$, $i = 2k - 1$ corresponds to the first element of $\mathbf{Z}_{kh}^1$ or Q_{kh}^0, $i = 2k$ corresponds to the second element of Z_{kh}^1 or Q_{kh}^1, and $\hat{B}_{-i}$ is the ith column of $\hat{B}$. Importantly, the second term on the righthand side of equation (4.25) permits the TSA expenditure elasticities to vary with the overall change in the level of environmental quality, $d\mathbf{Z}_h^1$. Thus, expenditure elasticities change with changes in the relative scarcity of environmental opportunities. Using equation (4.25), an r percent improvement in Q_{kh} from $\bar{Q}_{kh}^0$ to Q_{kh}^1 reduces minimum expenditure by $r\hat{c}_{ih}^1$ percent.

The TSA expenditure elasticities illustrate how estimates of **b** and **B** can be used compute a valid valuation of policy. For example, consider an individual h that initially enjoys the mean initial level of environmental amenities and a policy that would change Q^0_{kh} and Q^0_{lh} by r percent to Q^1_{kh} and Q^1_{lh}. Sequencing the change in Q^0_{kh}, first, and the change in Q^0_{lh}, second, yields a valuation

$$(4.26)\quad HC(Q^1_{kh},\bar{N}^0_h) = m^0(-c^1_{ih})(r/100)$$

$$= m^0(-\hat{b}_{ih} - dQ^1_{kh}\hat{B}_{ii})(r/100)$$

for the first-step change in Q^1_{kh} where i = 2k. For the second-step change in Q_{lh},

$$(4.27.1)\quad hc'(Q^1_{lh},N^1_h) = [m^0 - hc'(Q^1_{kh},\bar{N}^0_h)](-c^1_{jh})(r/100)$$

$$(4.27.2)\quad = m^0[1 + \hat{c}^1_{ih}(r/100)](-\hat{b}_{jh} - dQ^1_{kh}\hat{B}_{ij} - dQ^1_{hl}\ \hat{B}_{jj})(r/100)$$

where j = 2l and $\mathbf{N}^1_h$ encompasses the first-step change in Q_{kh}. Summing the independent valuation of Q^1_{kh} and the sequenced valuation of Q^1_{lh} would yield a valid total valuation, $hc'(Q^1_{kh},Q^1_{lh},\bar{\mathbf{N}}^0)$.

Equation (4.27) reveals the two types of substitution effects that may arise with a valid sequenced valuation, a direct effect and a compensation effect. The <u>direct</u> effect arises as $\hat{c}^1_{jh}$ changes with the first step change in Q_{kh}. In line (4.27.2), the direct effect is summarized by the term $dQ^1_{kh}\mathbf{B}_{ij}$. With the off-diagonal terms of $\mathbf{D}_{\mathbf{NN}}$ lne unrestricted in sign, the direct effect may be either complementary or competitive. A compensation effect arises due to the compensation necessary to maintain utility constant at u^0 after the first policy step. That is, before evaluating the second step of policy, discretionary income must be conceptually reduced by $hc'(Q^1_{kh}, \bar{N}^0_h)$. In line (4.27.2), the compensation effect arises due to the multiplicative term $[1 + \hat{c}^1_{ih}(r/100)]$. Because $[1 + \hat{c}^1_{ih}(r/100)] < 1$, the compensation effect is unambiguously competitive. As demonstrated earlier, only the compensation effect arises in the CD case.

While the elasticity approach illustrates the source of substitution effects, a second TSA procedure is more adaptable as policies become more complex. This second procedure recognizes that equation (4.24) is the log of the expenditure function. Directed by the valid BC design of equation (4.3), an arbitrary set of post policy impacts can be valued using equation (4.24). First, equation (4.24) is evaluated at the post policy level of environmental parameters and initial income. The expenditure function is then computed by taking the antilog of the lefthand side of equation (4.24). By computing the difference between initial income and the post policy value of the expenditure function, the valid BC outcome is obtained as in line (4.3).

The three scenarios described in Table 4.2 can be used to demonstrate the three steps of the second TSA estimation procedure. As shown by the left-hand column of Table 4.2., the individual enjoys or suffers an initial level of environmental quality that differs from the mean, $\bar{Z}^0$, only in dimensions k and l. In addition, the individual's discretionary income, M^0_h, also deviates from the mean, $\bar{M}^0$. In terms of post-policy levels, Scenarios I and II each propose a change in a single quality dimension: Scenario I impacts only on dimension k and Scenario II impacts solely on dimension l. Scenario III,

Table 4.2. A TSA Approach to the Evaluation of Public Policy

Scenario	Amenity-Income Level Initial	Amenity-Income Level Post-Policy	Policy Induced Change[1]	Expenditure Function Post-Policy Level
I	Z^0_{kh}, Z^0_{lh}, M^0_h $\bar{Z}^0_m$, all $m \neq k$	Z^1_{kh}, M^0_h $\bar{Z}^0_m$, all $m \neq k$	$dZ^1_{kh} = (Q^0_{kh} - \bar{Q}^0_k, Q^1_{kh} - \bar{Q}^0_k)$ $dZ^0_{lh} = (Q^0_{lh} - \bar{Q}^0_l, 0)$ $dM^0_h = (M^0_h - \bar{M}^0)$	$e(Z^1_{kh}, Z^0_{lh}, \ldots, \bar{Z}^0_m, \ldots, M^0_h)$
II	Same as Scenario I	Z^1_{lh}, M^0_h $\bar{Z}^0_m$, all $m \neq k$	$dZ^0_{kh} = (Q^0_{kh} - \bar{Q}^0_k, 0)$ $dZ^1_{lh} = (Q^0_{lh} - \bar{Q}^0_l, Q^1_{kh} - \bar{Q}^0_l)$ $dM^0_h = (M^0_h - \bar{M}^0)$	$e(Z^0_{kh}, Z^1_{lh}, \ldots, \bar{Z}^0_m, \ldots, M^0_h)$
III	Same as Scenario I	Z^1_{kh}, Z^1_{lh}, M^0_h $\bar{Z}_m$, all $m \neq k, l$	$dZ^1_{kh} = (Q^0_{kh} - \bar{Q}^0_k, Q^1_{kh} - \bar{Q}^0_k)$ $dZ^1_{lk} = (Q^0_{lh} - \bar{Q}^0_l, Q^1_{lh} - \bar{Q}^0_l)$ $dM^0_h = (M^0_h - M^0)$	$e(Z^1_{kh}, Z^1_{lh}, \ldots, \bar{Z}^0_m, \ldots, M^0_h)$

1) The TSA gradient and Jacobian are evaluated at the mean of the initial levels, $\bar{M}^0$.

however, encompasses the environmental impacts proposed by both Scenarios I and II. Given the policy induced change described by the third column of Table 4.2, the TSA structure can be used to compute the log of the post-policy expenditure level. With the post-policy expenditure level computed, net benefits can be calculated by equation (4.3); that is, by subtracting the post-policy expenditure level from initial income.

By combining the data given in Table 4.2 with the TSA structure, the log of post-policy expenditure can be computed. For Scenario I, the log of post-policy expenditure is

$$(4.28.1)\quad \ln e(Z^1_{kh}, Z^0_{lh}, \ldots, \bar{Z}^0_m, \ldots, M^0_h) = \bar{M}^0 + (dZ^1_{kh}, dZ^0_{lh}, dM^0_h) \begin{vmatrix} D_k \ln e \\ D_l \ln e \\ D_M \ln e \end{vmatrix}$$

$$(4.28.2)\quad + (1/2)(dZ^1_{kh}, dZ^0_{lh}, dM^0_h) \begin{vmatrix} D_{kk}\ln e & D_{kl}\ln e & D_{kM}\ln e \\ D_{lk}\ln e & D_{ll}\ln e & D_{lM}\ln e \\ D_{Mk}\ln e & D_{Ml}\ln e & D_{MM}\ln e \end{vmatrix} (dZ^1_{kh}, dZ^0_{kh}, dM^0_h)'$$

$$(4.28.3)\quad = \bar{M}^0 + (dZ^1_{kh}, dZ^0_{lh}, dM^0_h) \begin{vmatrix} b_1 \\ b_2 \\ b_3 \\ 0 \\ b_5 \end{vmatrix}$$

$$(4.28.4) \qquad + (1/2)/(dZ^1_{kh}, dZ^0_{1h}, dM^0_h) \begin{vmatrix} B_{11} & B_{12} & B_{13} & 0 & B_{15} \\ B_{21} & B_{22} & B_{23} & 0 & B_{25} \\ B_{31} & B_{32} & B_{33} & 0 & B_{35} \\ 0 & 0 & 0 & 0 & 0 \\ B_{51} & B_{52} & B_{53} & 0 & B_{55} \end{vmatrix} (dZ^1_{kh}, dZ^0_{1h}, dM^0_h)'$$

Because the second element of dZ^0_{1h} is zero, the conforming elements of **b** and **B** do not enter into the valuation of Scenario I. Therefore, b_4 and B_{4-} are given zero values in lines (4.28.3) and (4.28.4) to underscore the fact that a Scenario I valuation contains <u>no</u> information regarding a compensated change in Q_{1h}.

For Scenario II, the log of the post-policy expenditure level is

$$(4.29.1) \quad \ln e(Z^0_{kh}, Z^1_{1h}, \ldots, \bar{Z}^0_m, \ldots, M^0_h) = \bar{M}^0 + (dZ^0_{kh}, dZ^1_{1h}, dM^0_h) \begin{vmatrix} \mathbf{D}_k \ln e \\ \mathbf{D}_1 \ln e \\ \mathbf{D}_M \ln e \end{vmatrix}$$

$$(4.29.2) \qquad + (1/2)(dZ^0_{kh}, dZ^1_{1h}, dM^0_h) \begin{vmatrix} \mathbf{D}_{kk}\ln e & \mathbf{D}_{k1}\ln e & \mathbf{D}_{kM}\ln e \\ \mathbf{D}_{1k}\ln e & \mathbf{D}_{11}\ln e & \mathbf{D}_{1M}\ln e \\ \mathbf{D}_{Mk}\ln e & \mathbf{D}_{M1}\ln e & \mathbf{D}_{MM}\ln e \end{vmatrix} (dZ^0_{kh}, dZ^1_{kh}, dM^0_h)'$$

$$(4.29.3) \qquad = \bar{M}^0 + (dZ^0_{kh}, dZ^1_{1h}, dM^0_h) \begin{vmatrix} b_1 \\ 0 \\ b_3 \\ b_4 \\ b_5 \end{vmatrix} .$$

$$(4.29.4) \qquad + (1/2)/(dZ^0_{kh},dZ^1_{lh},dM^0_h) \begin{vmatrix} B_{11} & 0 & B_{13} & B_{14} & B_{15} \\ 0 & 0 & 0 & 0 & 0 \\ B_{31} & 0 & B_{33} & B_{34} & B_{35} \\ B_{41} & 0 & B_{43} & B_{44} & B_{45} \\ B_{51} & 0 & B_{53} & B_{54} & B_{55} \end{vmatrix} (dZ^0_{kh},dZ^1_{lh},dM^0_h)'$$

Again, in the valuation of Scenario II, certain elements of **b** and **B** are unimportant to a valid first-step valuation. Specifically, since the second element of dZ^0_{kh} is zero, b_l and B_{-l} may take on an arbitrary value without altering the first-step valuation of Z^1_{lh}.

Finally, the valid overall valuation of Scenario III is

$$(4.30.1) \quad lne(Z^1_{kh},Z^1_{lh},\ldots,\bar{\bar{Z}}^0_m,\ldots,M^0_h) = \bar{M}^0 + (dZ^1_{kh},dZ^1_{lh},dM^0_h) \begin{vmatrix} \mathbf{D}_k lne \\ \mathbf{D}_l lne \\ \mathbf{D}_M lne \end{vmatrix}$$

$$(4.30.2) \qquad + (1/2)(dZ^1_{kh},dZ^1_{lh},dM^0_h) \begin{vmatrix} \mathbf{D}_{kk} lne & \mathbf{D}_{kl} lne & \mathbf{D}_{kM} lne \\ \mathbf{D}_{lk} lne & \mathbf{D}_{ll} lne & \mathbf{D}_{lM} lne \\ \mathbf{D}_{Mk} lne & \mathbf{D}_{Ml} lne & \mathbf{D}_{MM} lne \end{vmatrix} (dZ^1_{kh},dZ^1_{kh},dM^0_h)'$$

$$(4.30.3) \qquad = \bar{M}^0 + (dZ^1_{kh},dZ^1_{lh},dM^0_h) \begin{vmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \\ b_5 \end{vmatrix} .$$

$$(4.30.4) \qquad + (1/2)/(dZ_{kh}^{1}, dZ_{1h}^{1}, dM_{h}^{0}) \begin{vmatrix} B_{11} & B_{12} & B_{13} & B_{14} & B_{15} \\ B_{21} & B_{22} & B_{23} & B_{24} & B_{25} \\ B_{31} & B_{32} & B_{33} & B_{34} & B_{35} \\ B_{41} & B_{42} & B_{43} & B_{44} & B_{45} \\ B_{51} & B_{52} & B_{53} & B_{54} & B_{55} \end{vmatrix} (dZ_{kh}^{1}, dZ_{1h}^{1}, dM_{h}^{0})'$$

For a policy that encompasses both Scenarios I and II all twenty-one parameters of the general TSA must be known or estimated. Thus, for a policy that affects K environmental attributes, (2K+2)(2K+3)/2 parameters must be known or estimated.

Given estimates for **b** and **B** as well as the amenity and income data in Table 4.2, equations (4.28), (4.29), and (4.30) could be evaluated and the antilog of the respective lne(•) computed. The final step would be to compute net benefits by subtracting the post-policy level of expenditure from initial income.

Nested Forms of the TSA

The TSA approach discussed above is quite general. Substitution effects are fully represented in valuation and, in estimation of the TSA structure, no apriori restrictions are placed upon the underlying expenditure relations. Estimation of the general TSA structure, however, requires substantial information. For the simple two-impact policy of equation (4.30), twenty-one parameters must be estimated in order to describe the general structure. For each additional impact appended to a k-impact policy, the number of additional parameters required to describe the TSA is (4k+7). As policy becomes more complex, the costs of estimation are likely to enforce a trade-off between generality and cost reducing restrictions.

In this section, three nested alternatives to the general TSA form are developed. By nested, it is meant that each alternative can be viewed as a special case of the TSA. A continuum of TSA forms each with progressively more flexibility but, simultaneously, with more severe data requirements are derived. Each alternative is approached in terms of (1) the restrictions that it imposes on the underlying expenditure relations and (2) the data required for estimation.

A Constant Elasticity Form (CEF).

As demonstrated above, the coefficients **b** and **B** can be used to compute expenditure elasticities. Elements of **b** enter the elasticity measure [equation (4.25)] as constants while elements of **B** describe how these constants change with a given change in environmental quality. If the environmental impact proposed by policy is small, one might suspect that the expenditure elasticities are relatively constant. In particular, if (1) environmental impacts are relatively small and (2) data is so sparse that **B** cannot be estimated, one might be forced to suppose that the expenditure elasticities are constant and **B** = **0**.

With **B** = 0, the TSA structure reduces to

$$(4.31) \qquad \ln e(\mathbf{q}_h^1, \mathbf{q}_h^0, m_h^0) = \bar{M}^0 + (dZ_h^1, dM_h^0)\mathbf{b}.$$

Taking the antilog of equation (4.31) yields

$$(4.32) \qquad e(\mathbf{q}_h^1, \mathbf{q}_h^0, m_h^0) = (m_h^0/\bar{m}^0)^{(-b_{K+1})} \prod_{k=1}^{K} (q_{kh}^0/q_{kh}^1)^{(-b_k)}\bar{m}^0$$

which is simply one variant of the Cobb-Douglas form. Therefore, if the direct substitution effects are reduced to zero by assuming **B** = **0**, the CD form is produced. As argued earlier, only compensation effects can arise with the CD form.

Together, the CD and TSA approaches describe two points on a continuum. The CD is simple, estimable on independent valuations, and nested within the TSA. However, the CD is restrictive regarding substitution effects and, as demonstrated below, may not even make use of all the information contained within the independent valuations. Below, two functional forms that lie between the CD and general TSA forms are discussed.

A Restricted Elasticity Form (REF)

The REF is derived by considering (1) potential data restrictions and (2) the plausible similarities that may be present among elements of **B**. Specifically, suppose at the outset that only a set of independent valuations are available. As discussed above, not all of the coefficients of **B** are estimable on the independent valuations alone. However, it is possible to investigate and use the structural similarity between the coefficients that <u>are</u> and the coefficients that <u>are not</u> estimable on a set of independent valuations. The REF form summarizes this investigation.

To ease the exposition, it is supposed that a set of independent valuations corresponding to Scenarios I and II of Table 4.2 are available as data. It is also assumed that a contingent valuation sample has been taken across households $h \in \{1,\ldots,H\}$ and that there is adequate variation in initial environmental quality. From lines (4.28.3) and (4.28.4) it can be seen that data on Scenario I permits one to estimate 13 of the 21 coefficients of the TSA. Specifically, valuation data on Scenario I can be used to estimate all TSA parameters except b_1, B_{41}, B_{42}, B_{43}, B_{44}, and B_{45}. Lines (4.29.3) and (4.29.4) , however, indicate that data on Scenario II can be used to estimate all the inestimable parameters except B_{42}. Thus, an adequate set of independent valuations would allow one to estimate all the parameters necessary for a valid total valuation except B_{42}.

B_{42} is clearly a crucial parameter since it summarizes the substitution relation between post-policy levels of environmental quality. However, if a case can be made for a compensated, general hedonic equilibrium [Rosen], a surrogate for B_{42} may be available. Given a compensated initial equilibrium and individuals otherwise similar in preferences, the substitution relation between initial environmental quality level, B_{31}, should be very similar to the substitution relation between post-policy levels of environmental quality. B_{31} may therefore proxy the value of B_{42}.

The restricted elasticity form (REF) is restricted, then, in the sense that it requires three ancilliary assumptions: (1) that sufficient variation exists in initial environmental quality levels, (2) that a compensated equilibrium exists, and (3) that differences in individual preferences can be fully accounted for by socioeconomic characteristics or similar observable individual characteristics. If these three requirements hold, B_{31} approximates B_{42}. Given restrictions (1) through (3), all parameters required for valid valuation are estimable upon a set of independent valuations.

A Constant Relative Rate Form (CRR)

In many cases the restrictions required for the REF may be inappropriate. Initial environmental quality may be fairly constant across individuals or grounds sufficient for a compensated equilibrium may not exist. Limited data may therefore impose the necessity of restricting the number of substitution terms to be estimated. In this case, the set of post-policy substitution terms are be of greatest interest.

Structural similarities between post-policy substitution terms can be used to identify possible estimation restrictions. For example, by carrying out the differentiation implied by line (4.28.2), the structural components of the substitution matrix, B_{lk}, are obtained,

$$(4.33.1) \quad B_{lk} = \mathbf{D}_k[\mathbf{D}_l \ln e]$$

$$(4.33.2) \quad = [(\mathbf{D}q_l q_{k\_}e)(q_l q_k)/e] - b_l b_k$$

Rearranging

$$(4.34) \quad B_{lk} = b_l b_k[\theta_{lk}/\theta_l - 1]$$

where $\theta_{lk} = \mathbf{D}q_l q_{k\_}e/\mathbf{D}q_{l\_}e$ is the rate of change in the marginal valuation of q_l with respect to a change in q_k and $\theta_k = \mathbf{D}q_{k\_}e/e$ is the rate of change in minimum expenditure with respect to a change in q_k.

There are three interesting attributes of equation (4.34). First, equation (4.34) shows that the substitution term is composed of both first order effects--b_l, b_2, and θ_k--and a second order effect, θ_{lk}. The ratio of θ_{lk} to θ_k compares the rate of change in the marginal valuation of q_l to the rate of change in minimum expenditure as q_k changes. Second, if θ_{lk} and θ_k are equal, θ_{lk}/θ_k equals one and B_{lk} vanishes. Finally, a variety of functional forms may be constructed by assuming that θ_{1k}/θ_k is constant. For instance, in the case of the CD, θ_{1k}/θ_k is constant and equal to one; thus, in the CD case, B_{1k} is equal to zero. To develop a family of functions, let

$$(4.35) \qquad B_{1k} = b_1 b_k A$$

where $A = \theta_{1k}/\theta_k - 1$ is a constant and is directly related to the rate of change in marginal valuations relative to the change in minimum expenditure that occurs with a change in environmental quality. Given equation (4.34), the post policy substitution term, B_{1k} is proportional to the product of the first order terms, b_1 and b_k.[4]

The constant relative rate (CRR) form takes line (4.35) as a description of the second order terms. To illustrate the full structure of the CRR, suppose that policy affects three different environmental parameters, $k \in \{1,2,3\}$, and shifts $\bar{Z}_1^0$ to Z_{1h}^1, $\bar{Z}_2^0$ to Z_{2h}^1, and $\bar{Z}_3^0$ to Z_{3h}^1. Under these conditions the structure of the CRR is

$$(4.36) \qquad \ln e(q_{1h}^1, q_{2h}^1, q_{3h}^1, \mathbf{q}^0, m^0) = \bar{M}^0 + (dZ_{1h}^1, dZ_{2h}^1, Z_{3h}^1, dM_h^0)\mathbf{b}$$

$$+ (1/2)(dZ_{1h}^1, dZ_{2h}^1, dZ_{3h}^1, 0) \begin{vmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & Ab_2b_2 & 0 & Ab_2b_4 & 0 & Ab_2b_6 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & Ab_4b_2 & 0 & Ab_4b_4 & 0 & Ab_4b_6 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & Ab_6b_2 & 0 & Ab_6b_4 & 0 & Ab_6b_6 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{vmatrix} (dZ_{1h}^1, dZ_{2h}^1, dZ_{3h}^1, 0)'$$

where A represents the constant substitution terms. Though most of the zeros in the substitution matrix are permitted due to the constancy of environmental quality across regions and the sampling from a single income class, the constant substitution term does reduce the number of parameter to be estimated by K-1 where K is the total number of parameters impacted by policy.

Conclusions Regarding the TSA

The flexibility of the TSA underscores the trade-offs that are likely to be made in actual valuation. While the general form approximates an arbitrary set of expenditure relations, actual implementation is likely to be cut short by the costs of estimation. The advantage of the TSA approach is that the trade-off between structural restrictions and data can be made explicit and precise. Given adequate project resources, the general TSA form can be estimated. If project resources are more binding, the TSA structure can be used to reduce data requirements by apriori restriction and to direct research toward estimation of the essential parameters. By selecting a structural form along the continuum from the CD to the general TSA, one can define a procedure appropriate to the budget and data available to the valuation effort.

The Impact of Substitution on Regulatory Benefits and Costs

The previous two sections present a range of alternatives for specifying the environmental portion of a valid BC design. However, at an abstract level it is difficult to assess the impact of such specifications on the ultimate problem of projecting valid measures of benefits and costs. To illustrate the impact of such designs on BC outcomes, this section simulates environmental benefits and cost measures for selected values of the substitution parameters.

To reduce both informational requirements and complexity, the simulation uses the modified CRR form described in Appendix 4A.

The basic data required for simulation are a set of IVS environmental benefit or cost estimates and a range of selected substitution parameters. For purposes of illustration, Table 4.3 lists five hypothetical, independent valuations for five hypothetical regulatory programs. The value data are presumed to correspond to twenty-five percent improvements in each of the five program areas. With these data, the first order terms, **b**, of the modified CRR from were computed following the procedures described in Appendix 4A. To simulate the impact of substitution, hypothetical valid valuations were computed for three selected values of A. Table 4.4 states results.

Table 4.4 illustrates the impact of the valid design in terms of both component and total benefits. Since program components are evaluated in alphabetical order, the benefits of Program A remains constant and equal across the hypothetical IVS and valid designs. Coming later in the selected sequence valuation, the valid component valuations of Programs B, C, D, and E do not remain constant. In particular, as last in the sequence of valuation, the benefits of Program E suffer most from competition. The quantitative reduction in both component and total valuations depends on the size of the substitution term and the consequent strength of substitution. For A equal to zero, both the component and total valuations are very close to the independent valuation. For A equal to five, Program E benefits decline by twelve percent and total benefits decline by nine percent. Finally, for A equal to fifteen, Program E benefits decline by thirty-one percent and total benefits by eighteen percent.

To illustrate the asymmetry between benefits and costs, the CRR was also used to simulate the costs of environmental deterioration. The first order

Table 4.3. Hypothetical Benefit Measures for Twenty-Five Percent Improvements[a]

Benefit Source	IVS Benefit Estimate (Billions of $)
Program A	11.0
Program B	17.0
Program C	7.0
Program D	15.0
Program E	26.0

a. Valuations are hypothetical and are not intended to reflect on any particular regulatory program. For purposes of illustration, data are assumed to be national benefit estimates. National disposable income is assumed to be $2500 billion.

Table 4.4. Selected Substitution Parmeters and the Benefits of Regulatory Improvements[a]

Benefit Source	Method of Computation[b]			
	Independent	CRR, A=0	CRR, A=5	CRR, A=15
Program A	11.0[c]	11.0	11.0	11.0
Program B	17.0	16.9	16.6	15.8
Program C	7.0	6.9	6.5	5.8
Program D	15.0	14.8	13.8	11.7
Program E	26.0	25.5	23.0	17.9
Total	**76.0**	**75.1**	**70.9**	**62.2**

a. Valuations are hypothetical and are not intended to reflect on any particular regulatory program. For purposes of illustration, data are assumed to be national benefit estimates. National disposable income is assumed to be $2500 billion.
b. The selected sequence of valuation evaluates the programs alphabetically.
c. Value data are in billions of dollars.

terms, **b**, of the CRR were computed using (1) the IVS cost measures given in Table 4.5 and (2) a twenty-five percent reduction in program impacts. Results indicate the understatement (in absolute value) of costs that may occur with IVS. For A equal to 5, IVS procedures understate the total costs of deterioration by eleven percent. For A equal to 15, the total cost of deterioration is understated by nineteen percent.

In summary, the simulation of environmental benefits and costs indicates the asymmetry between benefits and costs when evaluated with a valid design. If, as suggested in Chapter III, competitive effects dominate the evaluation of both environmental and market price changes, IVS procedures overstate the net benefits of policy change.

Concluding Comments

The objective of the Chapter was to specify the theoretically valid benefit cost design in an estimable functional form. The first specification examined was the CD form. The CD form illustrates the use of a functional structure in generalizing a set of value data and demonstrates the source of substitution effects in an valid BC design. However, the CD form does impose rather arbitrary restrictions on the underlying set of expenditure relations and did not make full use of the information contained within a set of independent valuations.

A Taylor series approximation to the valid aggregation design generalizes the structural approach to benefit evaluation design. The TSA form is parsimonious and flexible; it approximates an arbitrary set of expenditure relations with a minimum of structural form. Not surprisingly, such a general form demands substantial data in estimation. To overcome the data problem, several alternative

Table 4.5. Selected Substitution Parmeters and the Costs of Regulatory Deterioration[a]

Source of Cost	Method of Computation[b]			
	Independent	CRR, A=0	CRR, A=5	CRR, A=15
Program A	-11.0[c]	-11.0	-11.0	-11.0
Program B	-17.0	-17.1	-17.5	-18.2
Program C	-7.0	-7.1	-7.5	-8.3
Program D	-15.0	-15.2	-16.3	-18.4
Program E	-26.0	-26.5	-29.2	-34.6
Total	**-76.0**	**-76.9**	**-81.5**	**-90.5**

a. Valuations are hypothetical and are not intended to reflect on any particular regulatory program. For purposes of illustration, data are assumed to be national cost estimates. National disposable income is assumed to be $2500.
b. The selected sequence of valuation evaluates the programs alphabetically.
c. Value data are in billions of dollars.

forms are derived form the general TSA form. The derived designs allow the tradeoff between flexibility and information to be made precise.

Finally, to illustrate the prospects of a valid design, regulatory benefit and cost measures were computed using hypothetical data and selected substitution parameters. Competitive effects were shown to lead to the overstatement of benefits and the understatement (in absolute value) of costs. If, as suggested in Chapter III, competitive effects dominate the evaluation of both environmental and market price changes, IVS procedures overstate the net benefits of policy change.

Endnotes

1. The second-order TSA approach does not result is a function that is entirely without parametric restrictions [Gallant (1981), Christensen and Caves]. However, more general approaches such as the Fourier flexible form [Gallant; Chalfant] are likely to be more data intensive.
2. Other, less costly, sampling plans are possible but are likely to introduce error correlations that would violate the OLS assumptions. These sampling plans and the appropriate econometric procedures are the subject of ongoing research.
3. Prices are considered constant at this point. Therefore, the notation, **p**, for prices is left implicit.
4. Christensen, Jorgenson, and Lau discuss a similar form in the context of market goods demands systems.

Appendix 4A

Estimating Valid Benefit Measures from Aggregate Independent Valuations

Environmental benefits are typically reported as aggregate independent valuations. These aggregate independent valuations may be estimated, say, from aggregate demand relations or perhaps as the sum of individual contingent policy evaluations. If total benefits are computed directly as a simple sum of these aggregate independent valuations, the result is a biased IVS valuation. The problem, then, is (1) to determine how the independent valuations might be used to approximate a valid aggregate valuation and (2) to suggest the additional research required to complete this aggregate valuation.

To formulate the research problem within the context of previous sections, two assumptions are necessary. First, it must be assumed that the structures developed to describe the valuations of individuals also describe the structure of the aggregate valuations. Of course, since these aggregate independent valuations are conceptually the sum of the individual valuations, an assumption of structural similarity does not seem unreasonable as an approximation.

Second, one must select an appropriate structure. With the presumed paucity of data and limited research resources, a structure containing a minimum of unknown parameters is desirable. Nevertheless, the structure must be general enough to estimate (1) the expenditure elasticities and (2) the essential structure of competition or complementarity. Given these basic requirements, a minimum structure is selected: A structure consisting of (1) the vector **b** and (2) a substitution matrix **B** with zeros along the diagonal and a substitution term A that is constant across environmental quality. Letting initial environmental quality be constant across individuals, the resulting structure for a two element policy is

$$\text{(A1)} \quad \ln e(q^1_{1h}, q^1_{2h}, m^0) = M^0 + (dZ^1_{1h}, dZ^1_{2h}, 0)\mathbf{b}$$

$$+ (1/2)(dZ^1_{1h}, dZ^1_{2h}, 0)\begin{vmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & Ab_1b_2 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & Ab_1b_2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{vmatrix}(dZ^1_{1h}, dZ^1_{2h}, 0)$$

$$\text{(A1.1)} \quad = M^0 + b_1\ln(q^1_{1h}/q^0_{1h}) + b_2\ln(q^1_{2h}/q^0_{1h})$$

$$+ Ab_1b_2\ln(q^1_{1h}/q^0_{1h})\ln(q^1_{2h}/q^0_{2h})$$

where, by analogy with the individual structures, M^0 is the log of aggregate discretionary income.

To compute a sequenced or total valuation using line (A1.1), several sets of values must be known. First, one must know the extent of improvement or reduction in environmental quality. Interestingly, the absolute improvement in environmental quality is not necessary. Line (A1.1) requires that one know only the relative improvement, q^1_{kh}/q^0_{kh}, or, equivalently, the percentage change in environmental quality. Second, a level of aggregate discretionary income must be selected. Alternatives here are net national product (NNP), NNP minus governmental expenditures (G), or NNP minus G minus aggregate non-discretionary private expenditures. Finally, the parameters b_1, b_2, and A must be estimated.

Point estimates of the aggregate independent valuations contain enough information to approximate b_1 and b_2. To see this, remember that the aggregate IVS valuations, $ivs'(q^1_{1h},q^0_{1h})$ and $ivs'(q^1_{2h},q^0_{2h})$, are known by assumption. Each of these IVS valuations assumes that other environmental quality levels, q_{kh}, remain constant at initial levels. Therefore, since $q^1_{kh}/q^0_{kh} = 1$ and $\ln(1) = 0$, line (A1.1) can be used to write the IVS valuations as

$$\text{(A2)} \qquad ivs'(q^1_{1h},q^0_{1h},m^0) \;=\; m^0 \;-\; m^0(q^1_{1h}/q^0_{1h})^{b_1}$$

and

$$\text{(A3)} \qquad ivs'(q^1_{2h},q^0_{2h},m^0) \;=\; m^0 \;-\; m^0(q^1_{2h}/q^0_{2h})^{b_2}$$

where m^0 is the level of aggregate discretionary income. Rearranging (A2) and (A3) results in

$$\text{(A4)} \qquad b_1 \;=\; \ln\{[m^0 - ivs'(q^1_{1h},q^0_{1h},m^0)]/m^0\}/\ln(q^1_{1h}/q^0_{1h})$$

and

$$\text{(A5)} \qquad b_2 \;=\; \ln\{[m^0 - ivs'(q^1_{2h},q^0_{2h},m^0)]/m^0\}/\ln(q^1_{2h}/q^0_{2h}).$$

By equations (A4) and (A5), b_1 and b_2 can be computed given (1) a measure of aggregate discretionary income; (2) the set of independent valuations; and (3) the respective environmental impacts underlying the independent valuations.

The final unknown is the substitution parameter A. In order to estimate A, at least one aggregate sequenced valuation must be known. In terms of a change in q_{2h}, this aggregate sequenced valuation is

$$\text{(A6)} \quad hc'(q^1_{2h},q^0_{2h},q^1_{1h},m^0) = e(q^1_{1h},q^0_{2h},m^0) - e(q^1_{1h},q^1_{2h},m^0).$$

By substituting equations (A1.1), (A4), and (A5) into equation (A6) and rearranging, the substitution parameter is

$$\text{(A7)} \quad A = (a_3 - a_1 - a_2)/a_1 a_2$$

where $a_1 = \ln\{[m^0 - ivs'(q^1_{1h},q^0_{1h},m^0)]/m^0\}$, $a_2 = \ln\{m^0 - ivs'(q^1_{2h},q^0_{2h},m^0)]/m^0\}$, and $a_3 = \ln\{[m^0 - hc'(q^1_{2h},q^0_{2h},q^1_{1h},m^0)]/m^0\}$.

By the preceding arguments, the parameters of equation (A1.1) can be estimated using the following data: (1) an independent valuation of a change in q_{1h}; (2) an independent valuation a change in q^h_2; and (3) a sequenced valuation of either a change in q_{1h} or a change in q_{2h}. If only the independent valuations are known, the essential research task is to obtain a set of sequenced valuations in order to estimate A. Once b_1, b_2, and A are computed, structurally valid valuations can be produced (1) for any combination of environmental improvements and (2) for any single-step or sequenced valuation design.

Chapter V

SUMMARY AND CONCLUSIONS

Policy subject to benefit cost analysis is typically complex. Regulatory reform measures such as EO 12291 ensure that broad institutional and structural changes are subject to BC evaluation. Such changes shift the cost structures of firms and the opportunity sets of individuals. The complex and diverse interactions that result pose severe problems for BC evaluation. Nevertheless, the solution of conventional procedures is too simple: Policy interactions are routinely ignored and impacts are evaluated independently. Previous case studies suggest that conventional procedures result in substantial error [Hoehn and Randall; Lave; Braeutigam and Noll]. In light of such error, the primary objective of this study was to assess the prospects for an improved BC design. In this Chapter research results are reviewed and summarized.

Chapter II accomplished two of the five research objectives outlined in Chapter I: the structural restrictions of a valid BC design were identified and the sources of complementary and competitive effects in valuation were analyzed. The identified BC design suggests two different strategies for valid BC evaluation. The first approach is holistic and evaluates the aggregate impact of policy in a single step. The holistic approach underscores an important point: Unlike the piecemeal approach of conventional procedures, a valid BC design encompasses the overall or aggregate impact of policy.

The second approach partitions the overall policy outcome into its component impacts and values each impact sequentially. This valid disaggregate design has three essential characteristics. First, the total valuation obtained by summation of the sequenced, component specific valuations is identical to the HC measure obtained with the holistic design. Thus, the aggregate valuation objective is clear and well-defined. Second, to obtain the valid aggregate valuation via a disaggregate design, a sequence of valuation is selected and applied. A valid (polygonal) sequence of valuation arrays the components of policy from first until last and then evaluates each impact sequentially by changing one component at a time from its initial to its post policy level. Third, the component valuations are not unique but are conditioned on the selected sequence of valuation. Generally, each sequence of valuation yields a different set of component specific valuations.

Because the restrictions imposed by a valid design are severe, a qualitative analysis was carried out to assess the impact of conventional procedures on benefit cost outcomes. The analysis explored the sources of substitution effects in valuation and reached three conclusions. First, if environmental parameters are additively separable, competitive effects are certain. Such separability may be induced by household technology, by spatial or temporal separation, or by uncertainty via the expected utility property. In these cases, conventional BC procedures can be expected to systematically overstate the net benefits of policy change. Second, if environmental parameters are linked by direct consumption interactions, complementarity is possible. Furthermore, complementary effects must be strong enough to overcome the sources of competition that remain operative. Direct consumption linkages are therefore necessary but not sufficient for complementary effects.

Third, independence in valuation is possible if (1) environmental parameters are linked by specific consumption relations and (2) sources of complementarity and competition happen to sum exactly to zero. Given no general rationale for such an outcome, independence appears unlikely. Insofar as the conditions for competition and, to a lesser extent, for complementarity, seem far more probable than those required for independence, conventional benefit cost procedures are almost certain to result in erroneous benefit cost outcomes.

Chapter III considers the possibility that the error introduced by conventional procedures might cancel or average out as the number of evaluated impacts becomes large. Asymmetries in the structure of benefit and costs indicate a strong and contrary result. As the number of evaluated components becomes large, conventional procedures systematically overstate the net benefits of policy change.

To capture the essential features of the large number case, Theorem 3.1 of Chapter III begins with two basic concepts. First, Theorem 3.1 asserts that there are a large number of policy alternatives that appear beneficial when evaluated as the proximate incremental program to an existing set of baseline conditions--that is, when evaluated by conventional procedures. Second, Theorem 3.1 introduces economic scarcity and demonstrates that a budget-like resource constraint bounds the valid net benefit measure. By combining these two concepts, conventional procedures are shown to systematically overstate the net benefits of policy change as the number of evaluated components becomes large.

Left unresolved by Theorem 3.1 was whether conventional procedures actually misstate the sign of a valid benefit cost outcome. To address this question, the structure of the economy was detailed and a generalized form of the HC net benefit measure was derived. Notably, the restrictions of this more inclusive valid design were virtually identical to those discussed in Chapter II.

With the structure of the economy explicit, Theorem 3.4 of Chapter III examines both the size and sign of conventional benefit cost outcomes.

Theorem 3.4 begins with the assertion that policy change policy change is minimally costly--that the marginal costs of component change are positive. Combining the notion of minimal policy costs with the prior two assertions of scarcity and the desirability of at least the first incremental change, the valid measure of benefits is shown once again to be bounded. The aggregate costs of policy change, however, are shown to be strictly increasing and unbounded. With benefits bounded and costs unbounded, the valid measure of net benefits becomes negative as the number of evaluated components becomes large. The conventional measure, however, fails to account for the bound on benefits and remains strictly increasing, positive, and unbounded. Thus, as the number of evaluated components becomes large, conventional procedures misstate the the sign of net benefits and misidentify net loss policies as potential Pareto improvements.

The valid BC design opens two approaches to improvements in routine BC evaluation. First, the valid BC framework can be used as a guide to the design of specific BC studies. Given a set of initial conditions and a set of proposed impacts, a specific study may apply either the holistic or sequenced approach. The resulting BC outcomes then conform and are limited to a specific set of baseline conditions and, if the sequenced approach is taken, a specific sequence of valuation. A second, more adaptable approach to improving BC outcomes is to specify and estimate the expenditure system that underlies the valid design. With reasonable estimates of system parameters, BC outcomes could be adapted and projected as baseline conditions change.

Chapter IV takes the second approach and specifies a portion of the theoretically valid design in terms of two estimable functional forms. The first specification examined was the Cobb-Douglas (CD) form. The CD form was useful in illustrating the functional structure of the valid design and in demonstrating one source of substitution effects in valuation. Overall, however, the CD form imposed substantial restrictions on substitution relations and failed to make full use of the information contained in a set of independent valuations.

The second specification generalizes the structural approach by deriving a second order Taylor series approximation (TSA) to the valid BC design. The TSA form is parsimonious and flexible; it approximates an arbitrary set of expenditure relations with a minimum of structural form. Such generality, however, comes at the expense of substantial data requirements in estimation. To circumvent these data requirements, a range of functional forms can be derived from the TSA by placing parametric restrictions on the general form. Such restrictions result in a range of nested functional forms that include the CD. By selecting a structural form along the continuum from the CD to the TSA, a parametric system can be defined that is appropriate to the data and budget available to the valuation effort.

To illustrate the prospects of a valid BC design, Chapter IV ends with a simulation of BC outcomes under a range of substitution parameters. Competitive effects are shown to lead to the overstatement of benefits and the understatement of costs. Results demonstrate that even a small step along the continuum between the CD and TSA may substantially improve the reliability of BC outcomes.

REFERENCES

Andrews, Richard N.L., "Economics and Environmental Decisions, Past and Present," in V. Kerry Smith, ed., Environmental Policy Under Reagan's Executive Order: The Role of Benefit-Cost Analysis, Chapel Hill: University of North Carolina, 1984.

Apostol, Tom M., Calculus, Waltham, MA: Blaisdell, 1962.

Arrow, Kenneth J., and Hahn, F.H., General Competitive Analysis, Amsterdam: North Holland, 1978.

Bergland, Olvar, and Alan Randall, "Operational Techniques for Calculating the Exact Hicksian Variations from Observable Data," Department of Agricultural Economics, Staff Paper 177, University of Kentucky, 1984.

Bockstael, Nancy E., and Kenneth E. McConnell, "Welfare Measurement in the Household Production Framework," American Economic Review, 83(4), September 1983.

Braeutigam, Ronald, and R., Roger G. Noll, "The Regulation of Surface Freight Transportation: The Welfare Effects Revisited," Review of Economics and Statistics, 66(1):80-87, February, 1984.

Brookshire, David, Alan Randall, and John R. Stoll, "Valuing Increments and Decrements in Natural Resource Service Flows," American Journal of Agricultural Economics, 60(3):478-488, August, 1980.

Chalfant, James A., "Comparison of Alternative Functional Forms with Application to Agricultural Input Data," American Journal of Agricultural Economics, 66(2):216-220, May, 1984.

Chipman, John S., and James C. Moore, "Compensating Variation, Consumer's Surplus and Welfare," American Economic Review, 70(5):933-949, December, 1980.

Christensen, Laurits, R., Dale W. Jorgenson, and Lawerence J. Lau, "Transcendental Logarithmic Utility Function," American Economic Review, 65(3):367-383, June, 1975.

Christensen, Laurits, R., and Douglas W. Caves, "Global Properties of Flexible Functional Forms," American Economic Review, 70:422-432, 1980.

Chung, Kai Lai, A Course in Probability Theory, New York: Harcourt, Brace, and World, 1968.

Deaton, Angus, and John Muellbauer, Economics and Consumer Behavior, London: Cambridge, 1980.

Dupuit, Jules, "De La Mesure de l'Utilite des Travaux Publics," Annales des Ponts et Chaussees, 8, 1844, translated in International Economics Papers, 2:83-110, 1952.

Fraas, Arthur G., "Benefit-Cost Analysis for Environmental Regulation," in V. Kerry Smith, ed., Environmental Policy Under Reagan's Executive Order: The Role of Benefit-Cost Analysis, Chapel Hill: University of North Carolina, 1984.

Freeman, A Myrick III, The Benefits of Environmental Improvement: Theory and Practice, Baltimore: John Hopkins, 1979.

Freeman, A. Myrick III, Air and Water Pollution Control: A Benefit-Cost Assessment, New York: Wiley, 1982.

Fuss, Melvyn, Daniel McFadden, and Yair Mundlak, "A Survey of Functional Forms in the Economic Analysis of Production," in Melvyn Fuss and Daniel McFadden, eds., Production Economics: A Dual Approach to Theory and Application, Amersterdam: North Holland, 1978.

Gallant, A. Ronald, "On the Bias of Flexible Functional Forms and an Essentially Unbiased Form: The Fourier Flexible Form," Journal of Econometrics, 15:211-245, 1981.

Gallant, A. Ronald, "The Fourier Flexible Form," American Journal of Agricultural Economics, 66(2):204-208, May, 1984.

Gorman, William M., "A Possible Procedure for Analyzing Quality Differentials in the Egg Market," Review of Economic Studies, 47:843-856, 1980.

Green, H.A. John, Aggregation in Economic Analysis, Princeton, 1964.

Hanemann, W. Michael, "Discrete/Continuous Models of Consumer Demand," Econometrica, 52(3):541-562, May, 1984.

Hausman, Jerry A., "Exact Consumer's Surplus and Deadweight Loss," American Economic Review, 71(4):662-676, September, 1981.

Heckman, James J., and Thomas E. Macurdy, "A Life-Cycle Model of Female Labor Supply," Review of Economic Studies, 47:47-74, 1980.

Hicks, J.R., "The Rehabilitation of Consumer's Surplus," Review of Economic Studies, February, 1941.

Hicks, John R., "The Four Consumer's Surpluses," Review of Economics Studies, 11:31-41, 1943.

Hicks, John R., A Revision of Demand Theory, Oxford: Clarendon Press, 1956.

Hoehn, John P., The Benefit Cost Evaluation of Multipart Public Policy: A Theoretical Framework and Critique of Estimation Methods, Ph.D., Dissertation, University of Kentucky, December, 1983.

Hoehn, John P., and Alan Randall, "Aggregation and Disaggregation of Program Benefits in a Complex Policy Environment," selected paper for the annual meetings of the American Agricultural Economics Association, August, 1982.

Hotelling, Harold, "The General Welfare in Relation to Problems of Taxation and of Railway and Utility Rates," Econometrica 6:242-269, 1938.

Just, Richard, Darrell L. Hueth, and Andrew Schmitz, Applied Welfare Economics and Public Policy, Englewood Cliffs: Prentice Hall, 1982.

Kneese, Allen V., Robert Ayres, and Ralph d'Arge, Economics and the Environment: A Materials Balance Approach, Baltimore: John Hopkins, 1970.

Lancaster, Kevin J., "A New Approach to Consumer Theory," Journal of Political Economy, 74:14-23, 1966.

Lave, Lester B., "Controlling Contradictions Among Regulations," American Economic Review, 74(3):471-476, June, 1984.

Majid, I., J.A. Sinden, and Alan Randall, "Benefit Evaluation of Increments to Existing Systems of Public Facilities," Land Economics, 59(4):377-392, November 1983.

Maler, Karl-Goran, Environmental Economics, Baltimore: John Hopkins, 1974.

Marshall, Alfred, Principles of Economics, 8th Edition, London: Macmillian, 1920.

Mishan, E.J., "A Survey of Welfare Economics, 1939-59," Economic Journal, 70:197-265, June, 1960.

Mishan, E.J., Cost-Benefit Analysis, New York: Praeger, 1971.

Navarro, Peter, "Clean Air Act Amendment: Energy, Environmental, Economic, and Distributional Impacts," Public Policy, 29:121-146, 1981.

Presidential Documents, Weekly Compulation of, 17(8):124-130, February 23, 1981.

Public Interest Economics Foundation, The Aggregate Benefits of Air Pollution Control, Washington, D.C.: Office of Policy Analysis, United States Environmental Protection Agency, June, 1983.

Quirk, James, and Ruben, Saposnik, Introduction to General Equilibrium Theory and Welfare Economics, New York: McGraw Hill, 1968.

Randall, Alan, "The Problem of Market Failure," Natural Resources Journal, 23:131-148, January, 1983.

Randall, Alan, John P. Hoehn, and George S. Tolley, "The Structure of Contingent Markets," presented to the annual meetings of the American Economics Association, Washington, D.C., December, 1981.

Randall, Alan, Berry Ives, and Clyde Eastman, "Bidding Games for Valuation of Aethetic Environmental Improvements," Journal of Environmental Economics and Management, 1:132-149, August, 1974.

Randall, Alan, and John R. Stoll, "Consumer's Surplus in Commodity Space," American Economic Review, 70:449-454, June, 1980a.

Randall, Alan, and John R. Stoll, "Economic Surplus and Benefit-Cost Analysis," Agricultural Economics Research Report 35, Department of Agricultural Economics, University of Kentucky, 1980b.

Scitovsky, T., "A Note on Welfare Propositions in Economics," Review of Economic Studies, 9:77-88, 1941.

Shoven, John B., and John Whalley, "Applied General-Equilibrium Models of Taxation and International Trade," Journal of Economic Literature, 22(3):1007-1051, September, 1984.

Silberberg, Eugene, "A Revision of Comparative Statics Methodology in Economics, or, How to do Comparative Statics on the Back of an Envelope," Journal of Economic Theory, 7:159-172, 1974.

Silberberg, Eugene, The Structure of Economics, New York: McGraw-Hill, 1978.

Small, Kenneth A., and Harvey S. Rosen, "Applied Welfare Economics With Descrete Choice Models," Econometrica, 49(1):105-130, January, 1981.

Smith, V. Kerry, ed., Environmental Policy Under Reagan's Executive Order: The Role of Benefit-Cost Analysis, Chapel Hill: University of North Carolina, 1984.

U.S. Flood Control Act of June 22, 1936. Section 1, 49 U.S. Statute, 1936.

Varian, Hal R., "A Third Remark on the Number of Equilibria of an Economy," Econometrica, 43:985-986, 1975.

Varian, Hal R., Microeconomic Analysis, New York: W.W. Norton, 1978.

White, Lawrence J., Reforming Regulation: Processes and Problems, Englewood Cliffs: Prentice-Hall, 1981.

Willig, Robert D., "Consumer's Surplus Without Apology," American Economic Review, 66:589-597, September, 1976.

Willig, Robert D., "Consumer's Surplus Without Apology: Reply," American Economic Review, 69(3):469-474, June, 1979.

Zeckhauser, Richard, "Preferred Policies When There is a Concern for Probability of Adoption," Journal of Environmental Economics and Management, 8:215-237, September, 1981.